Introduction

The EMF issue has been in the environmental debate since 1979, when Wertheimer and Leeper published an article suggesting a statistical association between certain characteristics of electrical powerlines near homes and the incidence of childhood leukemia (Wertheimer and Leeper, 1979). In the following 20 years, about $200 million of research funds were spent to determine the possible cause and effect relationship and the magnitude of this effect. In 1996, the National Research Council stated, “There is no conclusive evidence that EMF causes cancer” (National Research Council, 1996, p. 4). More recently, the National Institute of Environmental Health Sciences stated, “The scientific evidence suggesting that EMF exposures pose any health risk is weak,” but that “EMF exposures cannot be recognized as entirely safe, because of weak scientific evidence that exposures may pose a leukemia hazard” (National Institute of Environmental Health Sciences, 1999, Executive Summary, p. 1 and 2).

In 1995, the California Public Utilities Commission (CPUC) began funding a program to investigate various aspects of the EMF debate. The California Department of Health Services administered this program for the CPUC. One project, the “Power Grid and Land Use Policy Analysis,” was to examine engineering and land use alternatives that could reduce the exposure to EMFs. The objective of this project was to provide decision-makers with tools to develop and assess policy in light of the significant uncertainties about a possible EMF-health relationship. The project was not expected to provide recommendations. Instead it was expected to evaluate the costs and benefits of EMF management alternatives favored by various stakeholders and to determine what degree of confidence that a health hazard exists (if any) would be required to justify remedial actions. For those who wished to challenge the preliminary evaluations, a user-friendly computer model was developed to allow stakeholders or their technically knowledgeable advocates to modify the assumptions and to explore the consequences of these modifications.

This summary is a technical description of this project and its results. A less technical guide for decision makers and stakeholders is provided as a separate document (von Winterfeldt, 2001). This guide also includes descriptions of simplified models that decision makers and stakeholders can use to explore the implications of model assumptions and estimates.

The project considered all elements of the power grid system as possible sources of EMF exposure, including transmission lines, distribution lines, substations, and home grounding systems. The policy options include land use planning alternatives, retrofitting existing lines and facilities and re-designing new ones, standard setting, and other forms of regulation. Using decision analysis tools, the project considered a wide range of policy options, several scenarios involving a possible link between EMF exposure and health effects, and many objectives of different stakeholders. Special efforts were made to assess the environmental justice implications of policy options and to conduct a feasibility study of an assessment of property values near power lines and substations.

In the course of the project it became clear that many arguments about policy choices are really arguments about frameworks. Economists, engineers and regulatory agencies often use a predominantly results oriented "utilitarian" framework. Any given stakeholder using this framework considers his/her options along a number of criteria and chooses the option that produces the best trade-offs between the various criteria. In order to find the option with the best balance of criteria, the utilitarian stakeholder may assign dollar values to tangible criteria such as project costs and to intangible criteria such as aesthetic consequences or human lives saved

When different stakeholders using this approach end up advocating different courses of action because they have different interests, the utilitarian resolves the conflict by choosing the solution that aims at producing the "most good for the most people at the least cost." Sometimes this ignores the interests of some small segment of society. On many issues, members of the general public do not adhere to the utilitarian framework. Often they adhere either to a "social justice" framework that tries to fulfill duties or protect rights of the vulnerable regardless of cost, a "non interference" framework that tries to protect individual and property rights from governmental interference or a framework that requires virtual certainty of a problem before taking action.

Adherents to the different frameworks might prefer different policy options. For example if a municipality that owned its electrical utility decided that magnetic fields from power lines and appliances were hazardous and wanted to do something about it, the utilitarians in town might recommend that the municipal utility should pay for the most cost-effective measures to reduce exposure. As a result, they may advocate reducing EMF exposure from sources other than power lines, for example by replacing old, high exposure electric blankets and VDTs with new, low exposure models to prevent as much disease as possible due to electricity sources.

The adherents to the social justice framework might point out that the minority of people living next to the power grid were still at a higher risk. They might invoke the "precautionary principle" that risk avoidance policies are warranted even if there is uncertainty about whether or not there is a risk. Furthermore, they might argue that policy makers have a special duty to protect the minority of people exposed to the risk if it had been unfairly singled out for EMF or other harmful exposure on the basis of race, or had less access to medical care. From this perspective environmental agents like EMF should be treated as "guilty until proven innocent." Therefore the people living near the lines should be protected by modifying the lines to lower fields even if it was expensive to do so. They might also invoke a duty of the utilities "to clean up their own mess" at their expense.

The adherents to "non interference" might oppose both options because they would involuntarily tax the many for the benefit of the few. Regardless of the degree of confidence in the existence of an EMF hazard, they might prefer a "right to know" information program to allow the free market and voluntary actions of those who were concerned to solve the problem. Adherents to the "virtual-certainty-required" framework would not want to take any action unless all scientists in the field were convinced of a problem. For them EMFs are "innocent until proven guilty."

There is no technical resolution to these kinds of arguments. A democracy handles them through the political process. However, to address these issues, a decision analysis approach was used that was designed to be useful to adherents of all frameworks and to highlight issues where the different policy frameworks might lead to different conclusions. The intention was to assist decision-makers to anticipate how features of different policy options might be attractive to stakeholders who adhered predominantly to one or the other policy framework.

The decision analytic framework used in this power grid and land use project is consistent with the utilitarian framework, but it also addresses some of the concerns of the three other frameworks. First, rather than assuming that EMF is or is not a hazard, it asked what would be the minimum degree of confidence and the minimum magnitude of risk that would warrant actions. If a protective action is very inexpensive, even a low degree of confidence of a small risk can be justified in a decision analysis. If a protective action is very expensive, even complete confidence that EMFs cause a rare disease may not warrant this action from a decision analysis point of view. Second, instead of combining all the costs and benefits into a single number, the results are presented separately for each cost or benefit component (e.g., health cost, outage cost, property values benefits, etc.) so that if some costs or benefits pertain to one party and other costs or benefits to another, this is clearly presented for decision makers whose framework pays attention to the distribution of costs and benefits. Third, the decision analysis framework is presented in a way that allows stakeholders to use their own judgments about the facts and values concerning the costs and benefits of EMF mitigation.

While the decision analysis approach clearly separates the sources of costs and benefits, it does not make recommendations about how the costs and benefits should be allocated to stakeholder groups. For example, it is conceivable that the costs of EMF mitigation are allocated either to utility shareholders, the ratepayers, to residents who might benefit from the mitigation, or any mix of these groups. The analysis does not provide any guidance about the best allocation of costs and benefits. As a result, decision makers will have to rely on ethical and moral principles when making these allocation decisions. We conducted a workshop on ethics and environmental justice as part of this project, and some of the findings of this workshop help (see chapter 10 of the final report).

The project combined three approaches to address the fundamental uncertainties surrounding a possible EMF-health link:

1. *decision analysis* to incorporate the uncertainties and consequences of alternative policies,
2. analysis of alternative *exposure measures and dose-response functions* to capture a variety of possible biological relationships between EMF exposure measures and health effects,

3. a *stakeholder involvement process* to assure that a wide range of opinions, values, and concerns are incorporated in the policy analysis.

Decision analysis provided the overall framework for the policy analysis. The power grid and land use policy problem was first structured as a decision tree that started with policy alternatives (e.g., to mitigate by re-phasing or re-configuring existing lines), followed by several uncertain events regarding the resolution of the EMF issue (see Figure 1). For those unfamiliar with the term "decision tree" we recommend the image of walking along a road with many forks and branches. A traveler who ventures along any of these branches will find that each of them have further branches that could represent the chance that something does or does not happen as a result of the fork of the road chosen earlier. The decision tree is kind of a map to aid in keeping track of alternatives chosen, possible events, and the ultimate consequences that could result.   The decision tree in Figure 1 captures the major uncertainties about whether or not EMF exposure poses a hazard and how large the increase in risk is, measured as a risk ratio.

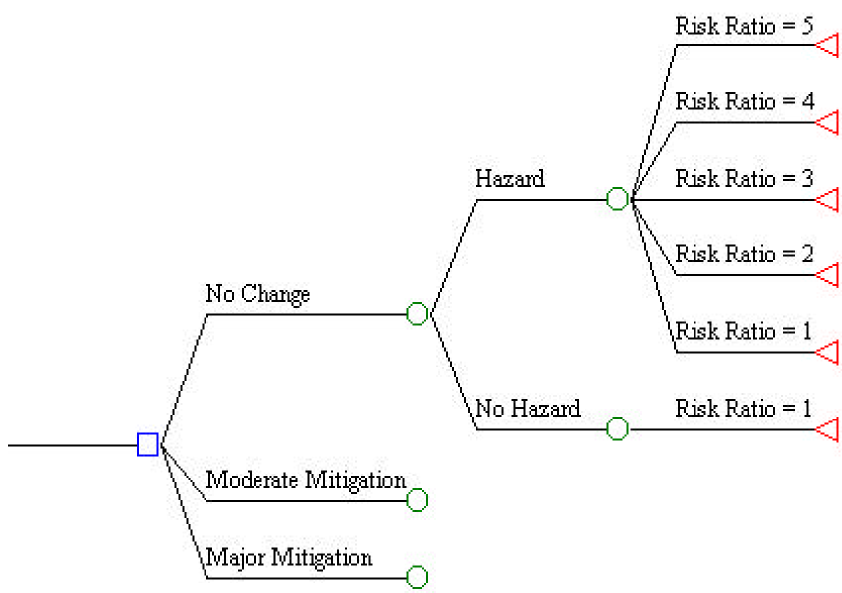


Figure 1: Schematic Decision Tree for Policy Analysis

(The square denotes a decision node, circles denote event nodes, and triangles denote end nodes at which consequences can be determined. Branches that end with a circle are completed by the tree above them.)

There also is significant uncertainty about what characteristic or measure of EMF exposure might be related to biological responses or doses. Possible measures include the time-weighted average of the magnetic field or the percent of time that a person is exposed to a field above a threshold. A significant effort was made in this project to estimate EMF exposure for different exposure measures and with different assumptions about the shape of the dose-response function.

At each end-node of the decision tree for which EMF is a hazard, health consequences occur. The project investigated the following health endpoints for which there is some epidemiological evidence of an EMF-health link: adult brain cancer, adult leukemia, female breast cancer, Alzheimer's disease, childhood brain cancer, and childhood leukemia. Mitigation options reduce EMF exposure and, if EMF poses a hazard, they will reduce health consequences. Because of the significant uncertainty about whether or not EMF is a hazard and what the magnitude of the hazard is, the decision analysis model was constructed primarily to explore the implications of different probabilities that a hazard exists and different degrees of severity of the hazard, if it exists. The main output of the decision analyses are two-way sensitivity analyses that answer the question: What is the minimum degree of confidence that a hazard exists and what is the minimum size of the health effect, that one would need to justify mitigation efforts?

Health consequences are not the only concern of the decision analysis. Others are direct dollar costs of mitigation, property value impacts, pole crashes, power outages, fires, electrocutions and many more. In total, the decision analysis considered 39 consequences, of which 20 are not EMF related. A useful way to summarize these non-EMF consequences of EMF policies is in the form of a consequence table. This table is not unlike the tables that one finds in Consumer Reports. Just like a family wanting to purchase a car might want to review a table in Consumer Reports comparing a variety of cars as to a number of criteria (e.g., price, fuel economy, durability, crashworthiness), we asked the stakeholders to list the policy options and the criteria by which they would evaluate the performance of each option (e.g., health risk from EMF exposure, direct dollar cost, electrocution risk). This sets up the consequence table, which is simply a blank table of alternatives vs. criteria.

To fill the consequence table with information about the alternatives, one can use a variety of methods. In Consumer Reports tables, we often find a mix of quantitative data (e.g., acceleration of a car expressed in the time it takes to reach 60 mph) and qualitative data based on expert judgment (e.g., dots where "good" is indicated by red dots and "bad" is indicated by black dots). Decision analysts attempt to use quantitative data wherever possible, because they describe consequences more clearly. Table 1 is an example of the non-EMF consequences of alternatives for retrofitting a 69 kV transmission line by either raising the pole height, by split phasing the line or by undergrounding it. For reference, the consequences of not changing the line are also included in this table. The consequences were calculated for a fifteen-mile stretch of the line with specific population and land use characteristics. Most consequences were calculated for a 35-year lifetime of the line. Total project cost, property-value benefits, construction fatalities and injuries, aesthetic impacts, and noise and disruption were calculated as a one-time consequence.

The consequences in this table are expressed in different units. For example, all fatalities are expressed in terms of expected life-years lost. In the case of the “No Change,” “Raise Pole Height,” and “Split Phase” alternatives one would expect 0.82 life-years to be lost due to fires during the 35 years of the line, none for undergrounding (see the first row of Table 1). Injuries are expressed in terms of the actual number of incidents. For example, one would expect 20.1 construction injuries to occur during the construction of a 15 mile stretch of underground line.

This consequence table is in itself helpful. It illustrates, for example, that among the monetary consequences total project cost and property value benefits are large and vary substantially across the four alternatives. Line losses are also large, but do not vary as much. All other monetary consequences are small by comparison. However, since the table includes consequences in many different units (e.g., life-years lost, customer-hours of service interruption, person-days of noise and disruption), it is hard to get a sense for the “bottom line” when comparing the alternatives.

Table 1: Non-EMF Consequences for a Decision to Retrofit a 69kV Powerline

	Alternatives			
Criteria	**No Change**	**Raise Pole Height**	**Underground**	**Split Phase**
Fire Fatalities (Years of Life Lost)	0.82	0.82	0.00	0.82
Fire Injuries (Number)	0.36	0.36	0.00	0.36
Collision Fatalities (Years of Life Lost)	3.18	3.18	0.80	3.18
Collision Injuries (Number)	0.06	0.06	0.02	0.06
Electrocutions - Public (Years of Life Lost)	1.00	1.00	0.18	1.00
Construction Fatalities (Years of Life Lost)	0.00	0.01	3.96	0.01
Construction Injuries (Number)	0.00	0.06	20.10	0.06
Electrocutions - Workers (Years of life Lost)	0.67	0.67	0.21	0.67
Total Project Cost (1998 Dollars)	$0	$1,655,000	$11,640,000	$2,321,000
Operation and Maintenance Cost (1998 Dollar)	$945,000	$945,000	$787,500	$945,000
Conductor Losses (1998 Dollars)	$6,542,000	$6,542,000	$8,137,000	$3,271,000
Property Values (1998 Dollars)	$0	$0	-$12,640,000	$0
Property Loss - Fires (1998 Dollars)	$57,850	$57,850	$0	$57,850
Property Loss - Collisions (1998 Dollars)	$16	$16	$4	$16
Outages - Contingencies (Hours)	138	138	36	138
Outages – Customer Interruptions (Customer-Hours)	275000	275000	71260	275000
Aesthetics (Constructed Scale)	0	0	-30	0
Trees (Equiv.Number of Trees Lost)	0	0	-120	0
Air Pollution (1998 Dollars)	$0	$0	-$98,460	-$8,038
Noise and Disruption (Person Days)	0	1517	35390	758

[1] All estimates are for 35 years. Dollar estimates are in 1998 dollars and not discounted. The estimate for total project cost includes all capital costs and assumes no financing.

To make consequences comparable, we used the standard cost-benefit approach to convert the units in all criteria into equivalent dollar costs. For example, we converted one life-year lost into an equivalent cost of $100,000, one serious injury into an equivalent cost of $10,000 and one person-hour of electricity disruption into an equivalent cost of $10. These are value judgments, which were based on a review of the economic literature on valuing health, safety, and other impacts. By multiplying the consequences in Table 1 by their unit equivalent cost, we calculated the total equivalent cost for all consequences. The result is shown in Table 2. This table shows that total project cost, conductor losses, property value benefits, operation and maintenance, and outages have large equivalent dollar values (from about $1 million to several million). All others are relatively small and thus are less likely to make a difference in the decision.

Table 3 shows a summary of the equivalent cost and the total equivalent cost of the four alternatives added up across criteria. In this example, the “No Change” alternative has the least equivalent cost (about $7.5 million), next is “Split Phase” with $10.1 million, followed by “Raise Pole Height” with $10.8million, and “Underground” with $16.7 million. Thus, split phasing is about $2.6 million more expensive than not to change the line, raising the pole height is $3.3 million more expensive, and undergrounding is $9.2 million more expensive. Note that these costs are for a fifteen-mile stretch of line and for 35 years.

Table 2: Non-EMF Equivalent Cost for a Decision Whether to Retrofit a 69 kV Powerline

	Alternatives			
Criteria	**No Change**	**Raise Pole Height**	**Underground**	**Split Phase**
Fire Fatalities (Years of Life Lost)	$81,780	$81,780	$0	$81,780
Fire Injuries (Number)	$3,616	$3,616	$0	$3,616
Collision Fatalities (Years of Life Lost)	$318,400	$318,400	$79,600	$318,400
Collision Injuries (Number)	$638	$638	$160	$638
Electrocutions - Public (Years of Life Lost)	$99,980	$99,980	$18,150	$99,980
Construction Fatalities (Years of Life Lost)	$0	$1,188	$396,000	$1,188
Construction Injuries (Number)	$0	$603	$201,000	$603
Electrocutions - Workers (Years of life Lost)	$67,110	$67,110	$21,000	$67,110
Total Project Cost (1998 Dollars)	$0	$1,655,000	$11,640,000	$2,321,000
Operation and Maintenance Cost (1998 Dollar)	$945,000	$945,000	$787,500	$945,000
Conductor Losses (1998 Dollars)	$6,542,000	$6,542,000	$8,137,000	$3,271,000
Property Values (1998 Dollars)	$0	$0	-$12,640,000	$0
Property Loss - Fires (1998 Dollars)	$57,850	$57,850	$0	$57,850
Property Loss - Collisions (1998 Dollars)	$16	$16	$4	$16
Outages - Contingencies (Hours)	$1,375,000	$1,375,000	$356,300	$1,375,000
Outages - Customer Interruptions (Customer-Hours)	$2,750,000	$2,750,000	$712,600	$2,750,000
Aesthetics (Constructed Scale)	$0	$0	-$300,000	$0
Trees (Equiv. Number of Trees Lost)	$0	$0	-$120,000	$0
Ait Pollution (1998 Dollars)	$0	$0	-$98,460	-$8,038
Noise and Disruption (Person Days)	$0	$15,170	$353,900	$7,583

[1]All cost estimates are for 35 years. The costs in this table are not discounted and the total project cost is not financed.

Table 3: Equivalent Cost for 69 kV Transmission Line Retrofit
(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Cost[1]	Outages	Property Values	Other (Non-EMF)	Total
No Change	$4,596,000	$2,533,000	$0	$386,400	$7,515,400
Raise Pole Height	$7,876,000	$2,533,000	$0	$402,200	$10,811,200
Underground	$28,550,000	$656,300	-$12,640,000	$157,300	$16,723,600
Split Phase	$7,190,000	$2,533,000	$0	$389,700	$10,112,700

[1]Cost includes total project costs, operations and maintenance cost, and conductor losses.

These equivalent costs do not include the possible EMF consequences of the decision. One way to relate the results to EMF consequences is to compare the incremental costs of the mitigation alternatives to the potential health benefits that must be achieved, before these incremental costs are worth spending. To justify split phasing, for example, the EMF health risk reduction benefits must at least be worth $2.6 million. Using $100,000 per life-year saved, this would man that split phasing would be cost-beneficial, if 26 or more life-years would be saved by EMF reduction due to split phasing over 35 years. Assuming a forty-year life expectancy of an average aged person, this is equivalent to saving about half a life. Raising the pole height would require at least 33 life-years (a little less than one life) to be saved over 35 years, and undergrounding would require at least 92 life-years (about two lives) to be saved.

It is, of course, impossible to assess precisely what the expected benefits of EMF risk reductions might be, if any. However, these benefits will depend on three factors: The diseases that are suspected of being affected by EMF exposure, the degree of confidence that the associations for the suspected diseases are causal in nature (expressed in the decision analysis as probabilities p) and the size of the effect for different diseases (expressed in the decision analysis as a risk ratios RR, indicating how much more likely a person is to have health consequences with EMF exposure vs. without it). Without specifying numerical values for the values of p and RR, we can nevertheless come to useful conclusions, by varying them through their range and observing, which alternative has the lowest total equivalent costs at any combination of p and RR. The results can be represented in a sensitivity analysis graph as shown, for example, in Figure 2. For low values of p and RR, the lowest cost alternative is not to change the line. For example, if p=0.1 and RR=1.5, the "No Change" alternative wins. For higher values of p and RR, the alternative to split phase the line has the lowest cost. For example, if p=0.30 and RR=2, split phasing wins. Undergrounding and raising the pole height are never the preferred alternative, given the assumptions.

The graph shown in Figure 2 simplifies matters by assuming only four diseases (brain cancer, leukemia, breast cancer and Alzheimer's disease) and the same probability of a causal relationship and risk ratio for all diseases. When interpreting these sensitivity analyses graphs, it is important to recognize that each combination of the degree of certainty (p) and the risk ratio (RR) reflects a possible state of the EMF hazard. Nothing in this graph reflects how probable any of the combinations of p and RR are. In particular, the areas defining optimal actions (no change vs. split phasing in Figure 2) do not reflect any relative likelihood that one action is preferred over another. Had we truncated the degree of hazard at 0.5 and the risk ratio at 3, the relative sizes of the areas would have been very different, yet the line dividing the two areas would still be the same and the conclusions – under what combination of p and RR to chose no change vs. split phasing – would have remained the same.

Figure 2 defines the regions of p and RR for which either no change or split phasing are preferred. For illustration, we also calculated the equivalent cost components and total equivalent costs for some points in this region, typically for p=0.10 and RR=2. Figure 3 shows the results of these calculations in the form of a stacked bar chart of cost components. It clearly shows that cost, health risk, property values, and outages are the major factors influencing the decision. All other factors show up only as a sliver on the top of the bars.

Figure 3 illustrated several important points of the analysis. First, the total equivalent cost of an alternative is the sum of the component equivalent costs (health, direct cost, outages, and property values). Second, the “no change” alternative has costs, in particular the health costs and the costs of operation and maintenance and conductor losses. Third, property values are considered as a benefit of undergrounding. Some stakeholders have argued that they should be considered as a cost of overhead design and the model can accommodate this view both in tables like Table 3 and in Figure 3. Mitigation options can reduce total equivalent costs, primarily by reducing the costs associated with health effects.

All calculations of exposures, consequences, and equivalent costs were embodied in a user-friendly software package that affords many opportunities to specify alternative line types and configurations, land use patterns, population characteristics, and many other model parameters. Computer models were developed for ten scenarios, including scenarios for retrofitting existing powerlines, building new ones, and improving grounding systems in homes. The purpose was to facilitate sensitivity analyses and to generate insights into the decision problem, not to make policy recommendations.

It should be noted that, just as family members trying to buy a car will not value all criteria the same and therefore will not all want to buy the same car, so will stakeholders involved in the EMF debate differ in how to value criteria for EMF mitigation decisions and on the preferred alternative for EMF mitigation. Decision analysis can clarify the discussion in society and can increase the chance of finding a reasonable solution, just as Consumer Reports can facilitate, but not resolve, the family’s discussion about the car purchase.

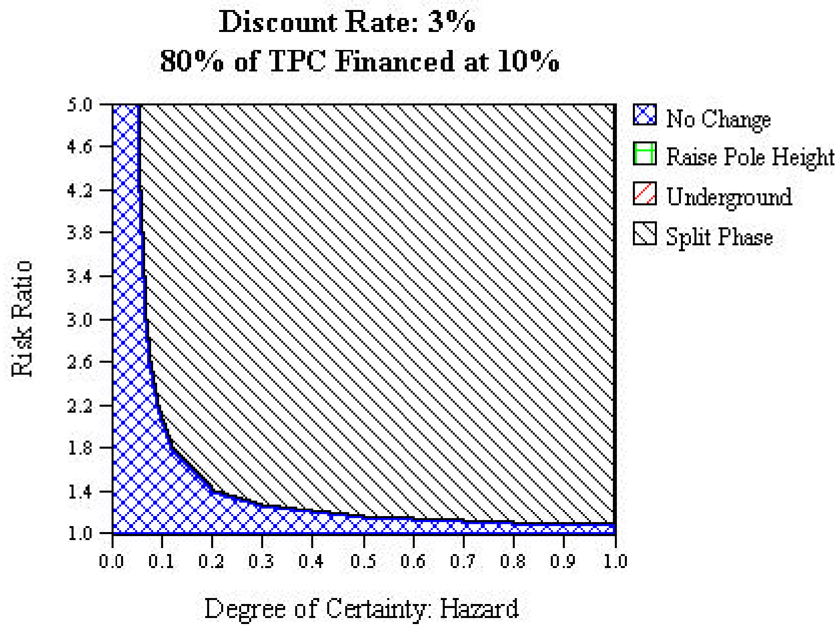


Figure 2: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA (All Health Endpoints)

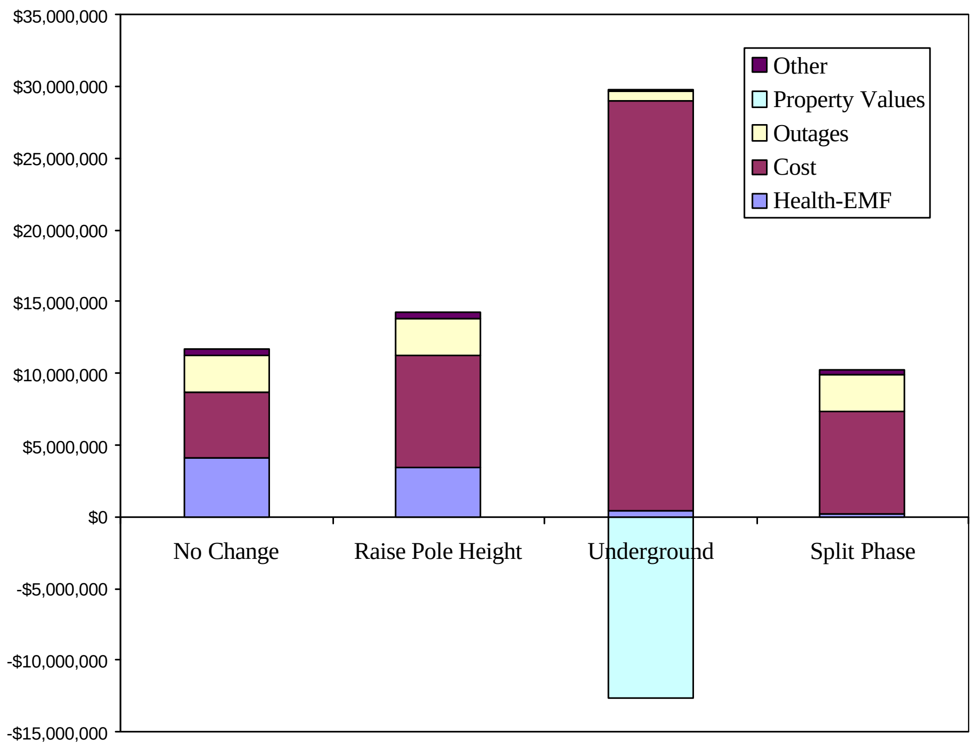


Figure 3: Stacked Bar Chart of Equivalent Cost Components for the 69kV Transmission Line Retrofit (3% Discount Rate, TPC Financed)

While good analysis can inform policy making, it is not sufficient in a situation of high scientific uncertainty and conflicting values. A *good process* that involves stakeholders from the beginning can do much to assure that the analysis is improved (by including the real concerns of the stakeholders) and that it is communicated better (by explaining the results to the stakeholders in their own terms). The project therefore followed a deliberate process of interacting with key stakeholders from the beginning of the project (to elicit their values and ideas for policy options) to the end (to obtain suggestions for model improvements).

Two additional efforts were made as part of this project. The first was an assessment of the environmental justice implications of alternative EMF policies affecting the power grid. For this purpose a workshop on environmental justice implications of EMF policies was conducted in April 1998. This workshop included presentations of the leading researchers and scholars in the field of environmental justice. The second effort was a review of the topic of property values near transmission lines and a feasibility study for a more detailed assessment of the impacts of EMF policies on property values. Feasibility studies were developed by a real estate appraisal firm and by an environmental economist.

The remainder of this summary provides a brief description of the major results of the project, following the chapter outline of the final report.

The California Power Grid

(Final Report, Chapter 2)

The California power grid has several sources of EMF exposure: transmission lines, primary distribution lines, secondary distribution lines, substations, and wiring and grounding systems in homes. There are about 43,000 circuit miles of transmission lines in California (see Table 4).

Table 4: Land Use Within 500 feet of California Transmission Lines

(Miles are Circuit Miles)

	Voltage Class (kV)			
	60-92kV	**101-161kV**	**220-287kV**	**>287kV**
Miles	14,841	10,352	12,630	5,108
Residential	6.0%	8.4%	6.0%	6.0%
Industrial, Commercial, Mixed	1.6%	4.5%	3.9%	4.3%
Rural, Agricultural, Open Space	92.4%	87.1%	90.1%	89.7%
Total	100.00%	100.00%	100.00%	100.00%

Only about 6-8% or 2,500 circuit miles pass through residential areas. We estimate that the 900 miles of lower voltage class transmission lines are single circuit and that the remaining 1,600 miles are double circuit. Since double circuit lines carry two circuits on each pole or tower, there will be 800 structure miles of double circuit lines. Assuming about 50 residences per mile on each side of the line, 170,000 homes would be affected. If each home has three residents, 510,000 people in California would be exposed to high fields.

There are many more miles of distribution lines (320,000 miles of overhead lines and 100,000 miles of underground lines), about half of which are primary distribution lines, the other half are secondary lines. Because distribution lines are everywhere, it is very difficult to obtain good estimates of how many miles of these lines can potentially affect fields in homes. High fields are mostly due to the primary overhead distribution lines. Lee et al. (2001) provide a limited data set on exposures from several sources, including transmission lines, distribution lines, and grounding systems. This data set describes a random sample of homes in a largely suburban area of Northern California. Table 5 shows the number of homes by wire code and the percentage of homes that exceeded a time-weighted average (TWA) reading of 2 mG, depending on wire code. The number of people affected were calculated by multiplying the California population of 33 million with the percentage shown in the column "% in Code and > 2mG."

Table 5: Classification of Homes in California by Wire Code (Source: Lee et al., 2001, sample size: 611 homes, Northern California)

Wire Code	Sources	% of Homes in Code	% above 2 mG	% in Code and > 2 mG	People > 2 mG
Very High	Transmission and Distribution	12.5%	15.0%	1.9%	618,750
Ordinary High	Distribution and Grounding	23.3%	9.3%	2.2%	715,077
Ordinary Low	Distribution and Grounding	26.8%	7.3%	2.0%	645,612
Underground	Grounding	37.4%	5.0%	1.9%	617,100
TOTAL		**100%**	**7.9%**	**7.9%**	**2,596,539**

Because of the possibility that two or more sources contribute to exceeding 2 mG, it is difficult to attribute the number of people exposed to more than 2 mG to a single source. For example, some "very high" wire code lines are transmission lines. Yet, some transmission lines have underbuilt distribution lines and removing the transmission line may leave an elevated exposure from the distribution line. Even removing the distribution line might leave fields from improper grounding.

We separated out the sources by making some reasonable assumptions. First, we assumed that all of the lower voltage transmission lines with 900 miles in residential areas are located street side and have underbuilt distribution lines. Thus, about half of the transmission lines also have distribution lines that may cause exposures above 2 mG to about 310,000 people. Second, we assumed that distribution lines and home grounding systems are independent sources of exposure. According to Table 5 about 7% of all exceedances above 2 mG are due to either home grounding or distribution lines. From Zafanella (1993), we estimate that about 5% of homes have fields above 2 mG due to home grounding systems alone. Using these assumptions, we estimate that about two percent or 670,000 people in California's are exposed to 2 mG or more due to distribution lines in the absence of transmission lines. Adding the 310,000 people from underbuilt distribution line exposure, we estimate close to 1,000,000 people to have exposures above 2 mG from distribution lines overall. For each mile of distribution lines that produce fields above 2 mG, we estimated that there are 50 affected homes with 3 residents each. By dividing a million people by 150 people per mile we estimate that there would be about 6,700 miles of distribution lines that produce fields above 2 mG.

Grounding systems in homes are used to divert fault currents produced by short circuits or electrical malfunctions to reduce electrocution risk and fire hazards. The National Electric Code requires homes to be grounded to the main water pipe and to a metal grounding rod that is driven into the earth near the electric utility service panel. If the service neutral is corroded or otherwise not functioning as an effective return path, the current on the water pipe can be quite high. Judging from residential home surveys (Zafanella, 1993), grounding systems can contribute to elevated fields between 2.5% and 10% of homes. We used 5% as a base estimate, resulting in 1,650,000 people exposed to elevated fields due to home grounding systems.

There are about 2,300 substations in the California electric utility grid. Many of these facilities have very high fields in their close vicinity primarily because of the high current lines that they are connected to. The fields from the transformers are also high, but they drop off rapidly with increasing distance. The original proposal by Decision Insights, Inc. had envisioned a special policy analysis module for substations. However, workshops with decision-makers and stakeholders revealed less interest in substations than in power lines. Furthermore, the policy options regarding substations are quite limited. For new substations the obvious policy option is to develop siting and land use restrictions. For existing substations, there are very few inexpensive options to reduce the fields. As a result, the project did not analyze substations. Instead, more intensive efforts on power lines were undertaken.

Table 6 summarizes the sources of elevated exposure to EMFs, the associated miles or homes, as appropriate, and the exposed population.

Table 6: Estimates of Sources (Miles of Powerlines or Homes) and People Exposed to 2 mG or More

Source	Miles/Homes	Population Exposed > 2 mG
Transmission	1,700 miles	510,000
Distribution	6700 miles	1,000,000
Home Grounding	550,000 homes	1,650,000
TOTAL*		**2,596,539**

*The total number of exposed people estimated by Lee et. al (2001) is smaller than the sum of the number of people affected by each source, because of an overlap between sources.

Decision Framing

(Final Report, Chapter 3)

A decision frame specifies the decision maker(s), the decision alternatives, and the decision objectives. For decision problems with multiple stakeholders, it is important to involve the stakeholders in the development of the decision frames. To better define the decision frames, four workshops were held in January 1997, three with potential decision-makers and one with other stakeholder groups. Representatives of the major regional California utilities, state regulators, and smaller municipal utilities participated in the first three workshops. Residents concerned with powerlines, ratepayer representatives, union representatives, and individuals concerned with health risks participated in the fourth workshop.

These workshops identified four major decision problems that should be studied in the project:

1. retrofitting existing transmission lines,
2. siting and configuring new transmission lines,
3. retrofitting distribution lines,
4. improving home grounding systems.

The workshops also created a comprehensive list of decision criteria, which should be considered when evaluating EMF policy alternatives (see Table 7). To the right of the criteria are the quantitative measures, which were used to guide the data collection and estimation process.

Exposure Calculations

(Final Report, Chapter 4)

Our policy models explore whether three different assumptions about dose measures and dose-response functions lead to different recommendations. The three assumptions are:

1. Time-Weighted Average (TWA): one simply ads up all the individual exposures during the course of a given time period and takes the average. This assumes that very low exposures convey some risk and should be added in with high exposures. We then assume that the risk increases in a steady linear fashion as this average increases until some plateau of risk is reached. If this assumption were true, one would want to avoid even low fields and would predict benefits from lowering moderately high fields to low fields.

2. Linear Threshold: there is no effect of the magnetic field exposure below a certain intensity ("threshold")? If this is so we should only average the fields which exceed that threshold. Exposures below the threshold convey no risk at all and are averaged in the exposure calculations as “zero” exposures. We still assume that the higher the exposure is above the threshold the more effect it has. We then assume that the risk increases in a steady linear

fashion as the average above the threshold increases until some plateau of risk is reached. If this assumption were true, one could ignore exposures below the threshold and would achieve benefits by lowering high fields down to moderately high fields.

3. Binary Threshold: there is no risk conveyed by readings below the threshold, and merely exceeding the threshold accumulates risk. It doesn't matter how much the exposure exceeds the threshold. If this is so, one should simply calculate the percent of the readings, that exceeded the threshold. We then assume that as this percent increases, the risk increases in a steady linear fashion up to some plateau of risk. If this assumption were true, one could ignore exposures below the threshold and would need to lower elevated fields to below that threshold to obtain any benefit. Lowering extremely high fields to fields above the threshold would convey no benefit at all.

Other assumptions, not investigated as part of this project, are that the relevant dose measure is the number of rapid field changes, the time spent in very high fields, or brief exposures to very high fields. However, it is possible to examine some of these assumptions with the existing software program. For example, if one is interested in brief exposures to very high fields, the linear threshold at 10 m would be an appropriate close measure, since there are usually very few of these high exposures.

To estimate exposure, we developed a software program that combines a probabilistic estimate of currents in powerlines, an exposure calculation, inclusion of background exposure, and determination of individual and group exposures evaluated for the different dose measures. The program is still research grade. It has a user-friendly front end that lets users define a variety of power line configurations, load conditions, and right-of-way widths. An example of an input screen is shown in Figure 4.

A typical output is shown in Figure 5 for a 69 kV transmission line with a maximum load of 600 Amps. This graph shows the exposure profile for the time-weighted average exposure measure. An important issue was how this exposure profile would change with changes in the exposure measure. Figures 6 shows the exposure profile for a linear threshold at 2 mG. The peaks and the shapes of the exposure profiles are very similar to the TWA measure, but the average exposure is much lower at distances above 100 feet from the powerline, where the first row of houses would be found, since few exposures at that distance will exceed 2 mG. Nonetheless, since most of the exposure reduction from mitigation occurs within about 100 feet of this 69kV line, there is little difference in the theoretical health benefit predicted by a linear dose response or a 2 mG threshold dose response curve. For the 10 mG linear threshold measure (Figure 7), the peaks are reduced and there is virtually no exposure at distances exceeding 50 feet.

Table 7: Decision Criteria and Their Measures[1]

Decision Criteria	Measures
Health Effects - EMF	
Leukemia	
Brain Cancer	For cancer incidence: Number of cases
Breast Cancer	For fatal cancer: Life-years lost
Alzheimer's Disease	For Alzheimer’s: Number of cases
Health Effects - Accidents	
Fires	
Pole Collisions	For fatalities: Life-years lost
Electrocutions	For injuries: Number of cases
Construction	
Cost	
Total Project Cost	1998 dollars
O&M	1998 dollars
Power Losses	1998 dollars
Service Reliability	
Contingencies	Number of contingency hours
Customer Interruptions	Number of person-hours of interruption
Property Impacts	
Property Values	1998 dollar change in property values
Fire Losses	1998 dollars
Pole Collision Losses	1998 dollars
Environmental Impacts	
Aesthetics	Aesthetics point scale
Tree Losses	Number of trees lost
Air Pollution	Percent change of fossil fuel generation
Noise and Disruption	Person-days of noise and disruption
Socioeconomic Impact	
Gross Regional Product	1998 dollars
Employment	Percent change in employment
Implementation Concerns	
Equity and Env. Justice	Qualitative judgment
Practicality	Qualitative judgment
Compliance	Qualitative judgment

[1] A reviewer of this report pointed out that this list of criteria may include some double counting. In particular, according to the economic theory of hedonic pricing, property values should have been adjusted for other negative impacts of powerlines. Thus counting reductions in property vales together with other negative impacts may be double counting the impacts of powerlines. Without arguing the merits of hedonic pricing theory, we observe that any changes to powerlines will have impacts on all the criteria in Table 7. For example, undergrounding might potentially lead to increased property values, reduced health risks, and improved aesthetics, which are all very real changes to those affected.

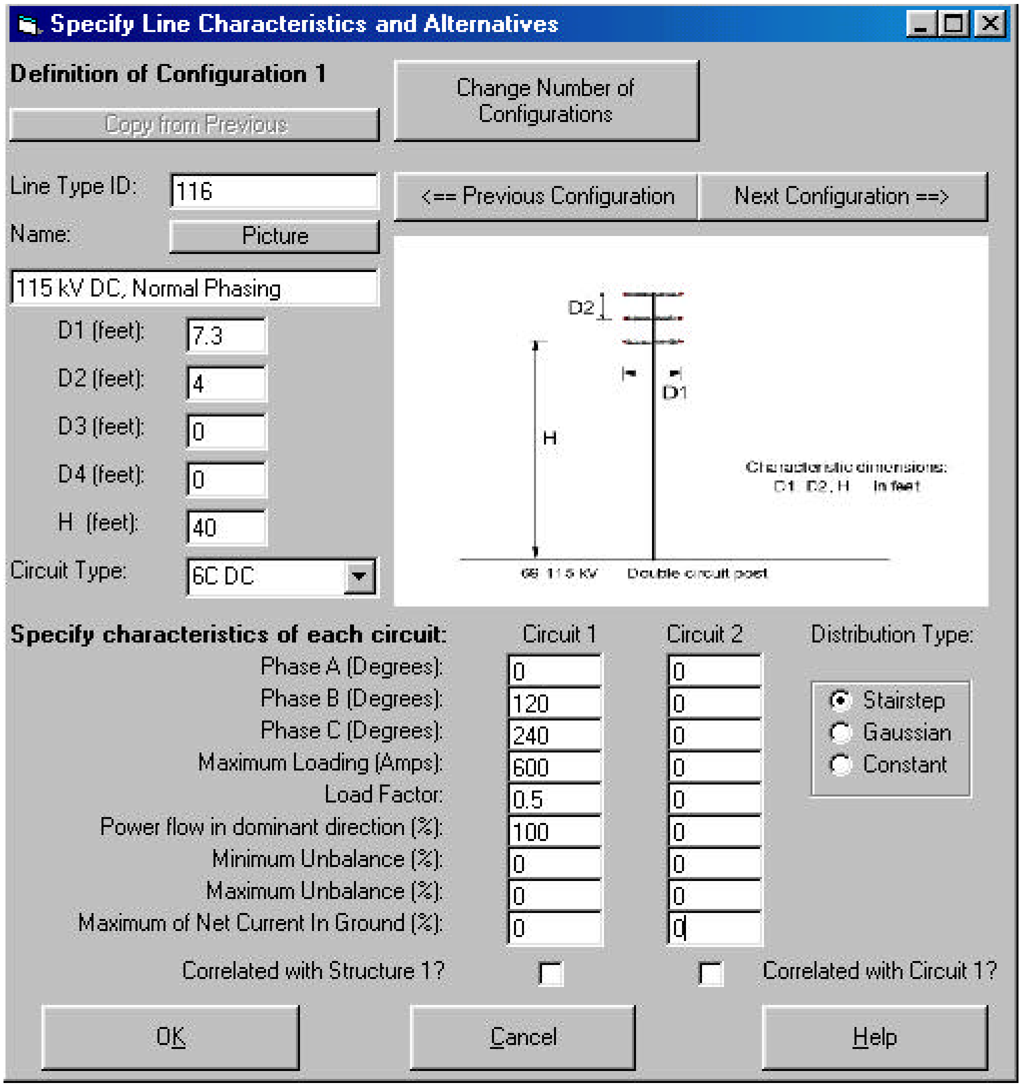
3. 

Figure 4: Input Screen for the Exposure Calculation Model

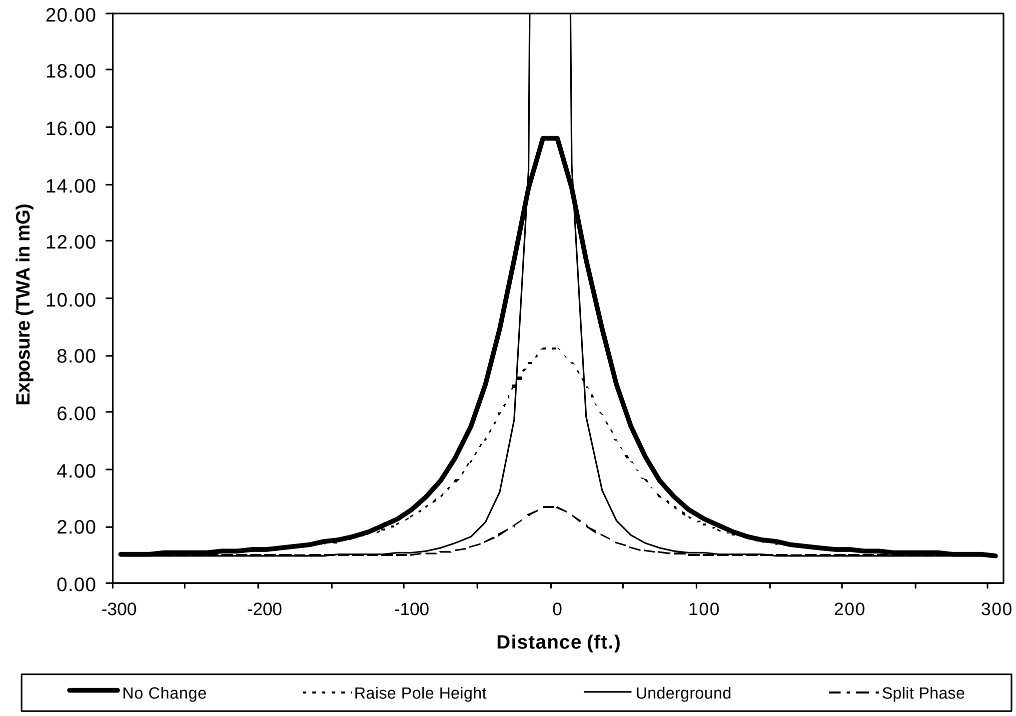


Figure 5: Per-Person Exposure (Time-Weighted Average) for a Transmission Line Retrofit Problem with Three Mitigation Alternatives

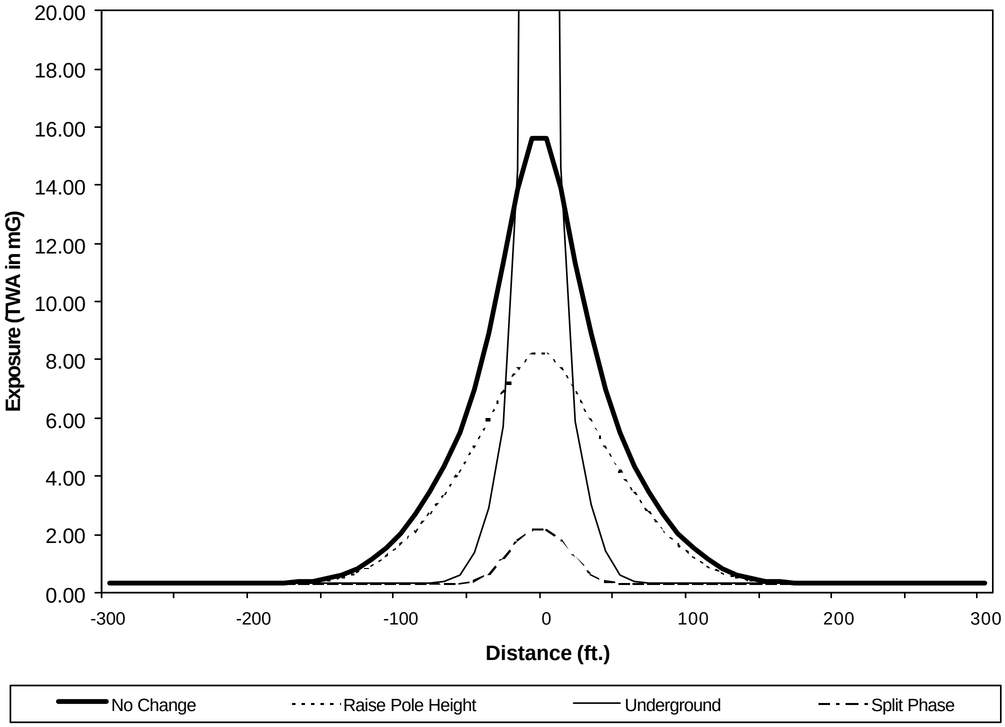


Figure 6: Per-Person Exposure (Linear Threshold at 2 mG) for a Transmission Line Retrofit Problem with Three Mitigation Alternatives

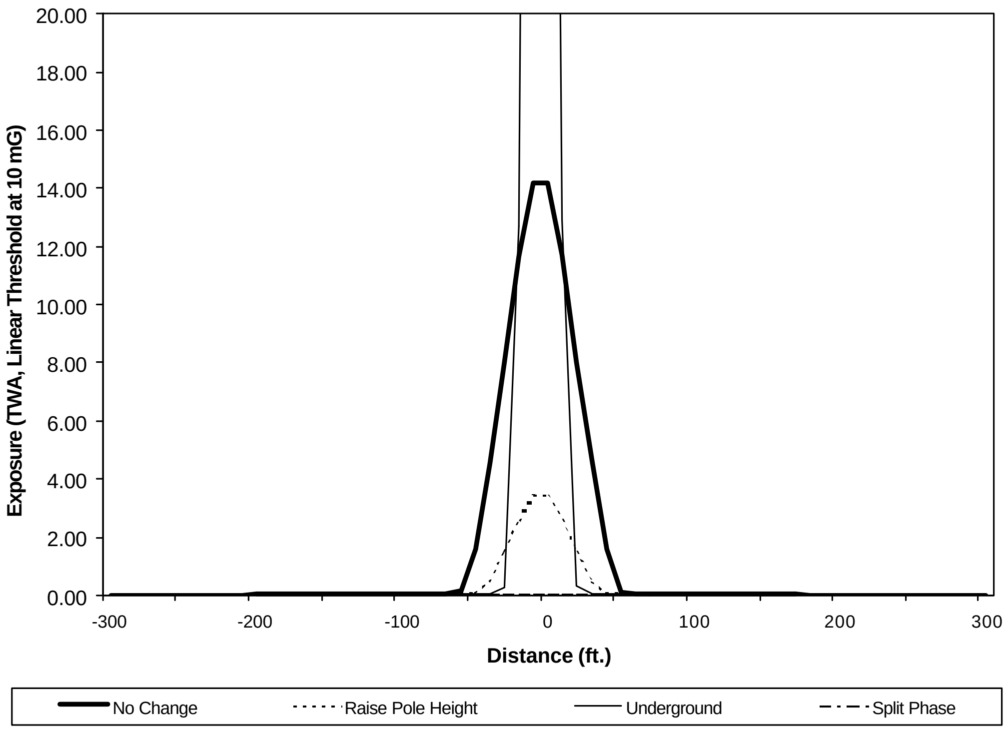


Figure 7: Per-Person Exposure (Linear Threshold at 10 mG) for a Transmission Line Retrofit Problem with Three Mitigation Alternatives

Risk Assessment

(Final Report, Chapter 5)

The risk model examined the following health endpoint: adult leukemia, adult brain cancer, childhood leukemia, childhood brain cancer, female breast cancer, and Alzheimer's disease. In addition, users can specify their own health endpoints.

The decision tree in Figure 1 acknowledges the possibilities that EMF may pose a health hazard and users assign a probability to that event. To quantify the seriousness of the health effects, the models use a user-specified dose-response function. All dose response functions are either linear or piece-wise linear in the respective exposure measure. The "response" in the dose-response function is defined as the risk ratio – the ratio of the rate of health effects of people exposed to EMFs at a given dose divided by the rate of health effects of people not exposed to EMFs. Figure 8 shows an example of a dose-response function for the TWA exposure measure. Three parameters specify the dose-response functions: The intercept (RR=1 at zero exposure or at sub-threshold exposure), the slope (uniquely identified by the risk ratio at a medium exposure, for example, as RR=2 at 2 mG time-weighted average exposure) and the maximum risk ratio (in this case at RR=4). In the sensitivity analyses that lead to displays like Figure 2, the slope was varied from RR=1 (no effect at 2 mG exposure) to RR=5 (five-fold risk increase at at 2 mG exposure). The maximum risk ratio was always set at 5.

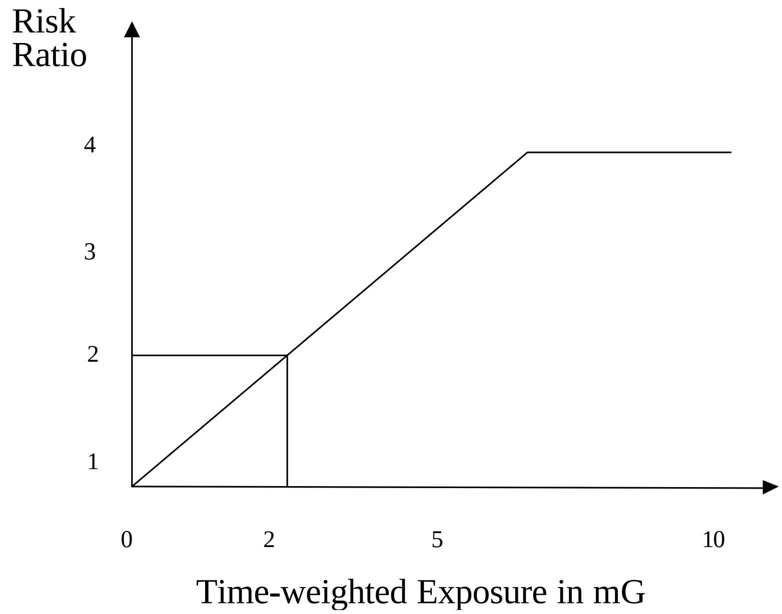


Figure 8: Example of a Linear Dose-Response Function for the TWA Effects Function

Assessment of Costs

(Draft Final report, Chapter 6)

Three cost components of EMF mitigation alternatives were estimated using data provided by Enertech Consultants: total project cost (TPC), operations and maintenance (O&M) cost, and line losses. Total project costs include design, engineering, management, and construction costs. O&M costs include tree trimming, repainting towers, replacing rotted wooden poles, and so forth. O&M costs can differ quite a bit from one strategy to the next, as for example when one alternative allows “live” maintenance while another requires the line to be taken out of service in order to be maintained. The costs of line losses are the costs associated with the heating up of the conductors, the heating up of the insulation surrounding the conductors (underground designs), or the heating up of the pipe for pipe-type underground designs. Losses can vary quite a bit as a function of which mitigation strategy is being evaluated.

Looking across the several powerline scenarios, the TPC for “moderate” mitigation measures (re-phasing, split phasing, delta configuration) was fairly low, between $1,000 and $50,000 per mile. Undergrounding, the more extensive mitigation alternative, costs between $750,000 and $4 million per mile. The cost of improving the home grounding system is a few hundred dollars per home. These cost estimates proved to be very controversial, especially for undergrounding. We therefore used two sets of cost estimates. The first (high) one assumed 80% financing of total project cost at a 10%

interest rate and 3% discount rate – resulting in approximately doubling the non-financed, undiscounted total project cost. The second (low) one assumed no financing and 3% discounting – cutting the non-financed, undiscounted project cost by about 30%.

O&M costs were also controversial, but they are much smaller than TPC, even when looking at a typical 35-year time horizon of the life of a line. O&M costs ranged from about $800 to $10,000 per mile per year. The higher costs were associated with pipe-type underground systems. Concrete type underground systems had comparable costs to overhead systems, typically about $1,000 per mile per year. Line losses were calculated based the typical load of a line (about 50% of ampacity) and cost of $0.03 per lost kiloWatt-hour. The cost of line losses can vary between $10,000 and $50,000 per mile per year. There is some controversy about the relative line losses of underground and overhead configurations. Our calculations indicate that underground configurations have smaller line losses, except for the higher voltage classes.

Because the cost estimation methodology was controversial, it was reviewed by Commonwealth Associates, Inc. (CAI, 2000). CAI concluded "… the unit prices reviewed were reasonable for the most part, but tended to be on the high side for overhead construction and on the low side for underground (10-20%)." In addition, we compared the cost estimates with estimates provided by utilities. In the final analyses, we did not use a single cost estimate, but a low cost and a high cost estimate, which provided a reasonable range of costs that included most estimates provided to us.

Assessment of Other Consequences

(Draft Final Report, Chapter 7)

Aside from health risks and costs, only two other consequences were large enough to make a difference to the decision: property values and outages.

Because so little is known about the property value impact of electromagnetic fields exposure, the property value model was developed with several possible scenarios in mind. The model divides property values impacts into those due to an EMF effect and those due to a non-EMF effect (aesthetics, noise, and radio interference). Most high-quality property values show some depreciation of properties near transmission lines, though much less is known about distribution lines. As a benchmark, the high-quality property values studies suggest that there is a property value reduction of around 5% for properties near transmission lines. It is very difficult to determine how much additional property value loss is due to EMF or what it would be, if EMFs were officially declared a hazard. Some argue that there is no loss due to EMF exposure; others argue that the loss might be as high as 20%. To accommodate a wide range of opinions, we conducted sensitivity analyses that varied property value impacts from a few percent to 20%. By making assumptions about housing density near powerlines, types of lines, and average property values, we calculated property values impacts to be between $500,000 and $4,000,000 per mile.

An argument can be made, of course, that EMF policies should not consider property value changes at all, but only the cost-effectiveness of exposure and health risk reduction. Of course, once we exclude property values, the door is open to arguing for the exclusion of all other non-EMF criteria in Table 6. Thus, this argument would lead us back to a straightforward cost-per-exposure reduction type of analysis, which is counter to the spirit of decision analysis to include all impacts of power grid policies. Nevertheless, to provide users of the analyses with insights about the effect of excluding property values, we conducted many sensitivity analyses with and without considering property value impacts.

If properties are depreciated due to the proximity to powerlines, there is also a reduction of property tax income. In contrast, undergrounding should lead to an increase in property values and in property taxes. However, this reduction and increase will be fairly small compared to the property value change itself (typically 1% per year). Even over the life-time of the powerline, this would be only about 1/3 of the property values impact and thus well in the range of our sensitivity analyses. Furthermore, most economists consider this type of cost or benefit to be a "transfer payment" between taxpayers and the beneficiaries of the tax with no net social cost or benefit. For this reason, we focused on the direct property value impacts in our analysis rather than on property tax impacts.

In the case of retrofitting existing powerlines the property values impact was expressed as an appreciation of currently depreciated properties. Residents who live near powerlines would like these impacts to be counted as a loss, in effect as a social penalty for overhead designs. In our models, the users can specify, which of these two views they would like to have represented. In the case of building new lines the property values impact was expressed as a depreciation of existing homes.

To better understand whether it is feasible to obtain high quality property values impact estimates for homes near powerlines in California and to determine what effort would need to be made to disentangle EMF and non-EMF effects, we conducted a property values feasibility study. To initiate this effort, we issued a "mock" request for proposal (RfP) that laid out the goals and requirements for a high quality property values study. We called it a "mock" RfP, because the intention was not to fund this study, but to obtain insights about its design, limitations, and cost.

Parkcenter Realty Advisors, a Southern California real estate appraisal firm was chosen to respond to this mock RfP, because some stakeholders concerned with property values considered real estate appraisers to be best qualified to conduct such a study. This company also had no ties to the utility industry, another concern of these stakeholders. Parkcenter Realty Advisors responded with a proposal that was based on a fairly simple case-control appraisal strategy. They estimated that the effort would take six months and cost $279,000. They also stated that it was virtually impossible to conduct a definite property values study (for any price) that would disentangle the effects of the EMF issue from other impacts of powerlines.

To make sure that we explored all possible research approaches regarding property values, we asked Dr. Gregory, a nationally known environmental economist, who is very familiar with the EMF issue, to submit another response to the mock RfP. His proposal included multiple methods and pays close attention to the EMF vs. non-EMF issue. He estimated the project time at 2 years and the cost at $800,000. However, even his proposal includes many caveats that current methods may not be able to disentangle the EMF effects on property values from the non-EMF effects.

This effort on estimating property values impacts has clarified two issues. First, property value impacts can be substantial, and they can outweigh the cost of mitigation. Second, to obtain a precise estimate of the EMF impact on property values is practically impossible. Utility staff members maintain that this impact is small and, to the extent that it exists, it should not be counted as a direct credit of mitigation. Residents believe that the impact is large (20% depreciation or appreciation is often quoted), and they insist that the impact should be counted as a penalty of overhead designs. Because of the uncertainty about these estimates, we conducted extensive sensitivity analyses on these percentages rather than using default values.

There are two criteria related to the service reliability of transmission lines: Contingencies and customer interruptions. Both begin with an outage, which occurs because of an equipment failure of a powerline, for example due to a tree hitting the line or due to wind toppling a power pole. An outage of a distribution line frequently leads to customer interruptions. However, because of the redundancy built into the transmission line network, an outage of a transmission line does not necessarily lead to customer interruptions. Yet, utility companies dislike transmission line outages, since they render the transmission system more vulnerable and require re-routing of electricity and changes in load ratings of the functioning lines. Utilities refer to a transmission line outage that does not lead to a customer interruption as a “contingency.”

For transmission lines the service reliability models calculate both the expected contingency time and the expected total customer interruption time. The estimates are based on a data set provided by the California Independent Systems Operator (ISO). As a general trend, this data set shows that the expected outage duration varies substantially between underground and overhead lines. For lower voltage classes, underground lines perform better, but for higher voltage classes, overhead lines perform better. This is primarily due to the longer repair times for high voltage underground lines. The equivalent costs of transmission line outages are between $1,000 and $10,000 per mile per year.

California utilities provided us with customer interruption data for underground vs. overhead distribution lines. This data generally favored underground lines, in some cases by a large margin. For one utility (San Diego Gas and Electric), underground designs had a larger number of customer interruption hours than overhead designs, if one counted planned outages for servicing the lines. Without counting planned outages, even this utility showed a better interruption performance for underground designs. The equivalent cost of distribution line outages is in the low thousands per mile per year.

All other consequences had equivalent costs that were in the tens or hundreds of dollars per mile per year. Thus, these other consequences could not make a difference to the EMF decisions. In the actual analyses, we lumped them together as “other cost,” and they typically show only as a sliver in graphical representations of the cost components of the EMF mitigation alternatives (see, for example, Figure 3 on page 10).

Scenarios and Computer Models

(Final Report, Chapter 8)

We developed computer models using the Analytica software program, for ten scenarios:

1. three scenarios for retrofitting transmission lines (69kV, 115 kV, and 230 kV),
2. three scenarios for siting and configuring new transmission lines (115 kV with different right-of-ways, routes, and land uses),
3. two scenarios for retrofitting distribution lines (3-wire and 4-wire configurations),
4. two scenarios for retrofitting home grounding systems

While these scenarios were fairly specific about the EMF sources and exposures, the models let the user change many parameters related to land use, population density, home values, etc. While most scenarios considered single family, single story homes, it is possible to extend them to multi-family, multi-story homes as well.

Figures 9 and 10 show the opening screens of the Analytica models. Users can initially run all calculations and obtain results with the base case model with the “mid value” parameters specified by us. In the “Settings” menu users can make many changes to these parameters.

The typical results will be illustrated with the 69 kV scenario and model. In this scenario an existing 69 kV transmission line passes a 15 mile residential area on street side poles. Mitigation alternatives are to split phase the line, to raise the pole height, or to underground it. The results of the exposure calculations (Figures 5-7, pages 19-21) show that TWA exposures can be above 10 mG within 50 feet of the line. Undergrounding increases the exposure just above the line, but it also reduces exposures rapidly as one moves away from the line to about 1.5 mG at 50 feet. Split phasing is quite effective in reducing exposure with about 2 mG at 50 feet. Raising the pole height is not very effective.

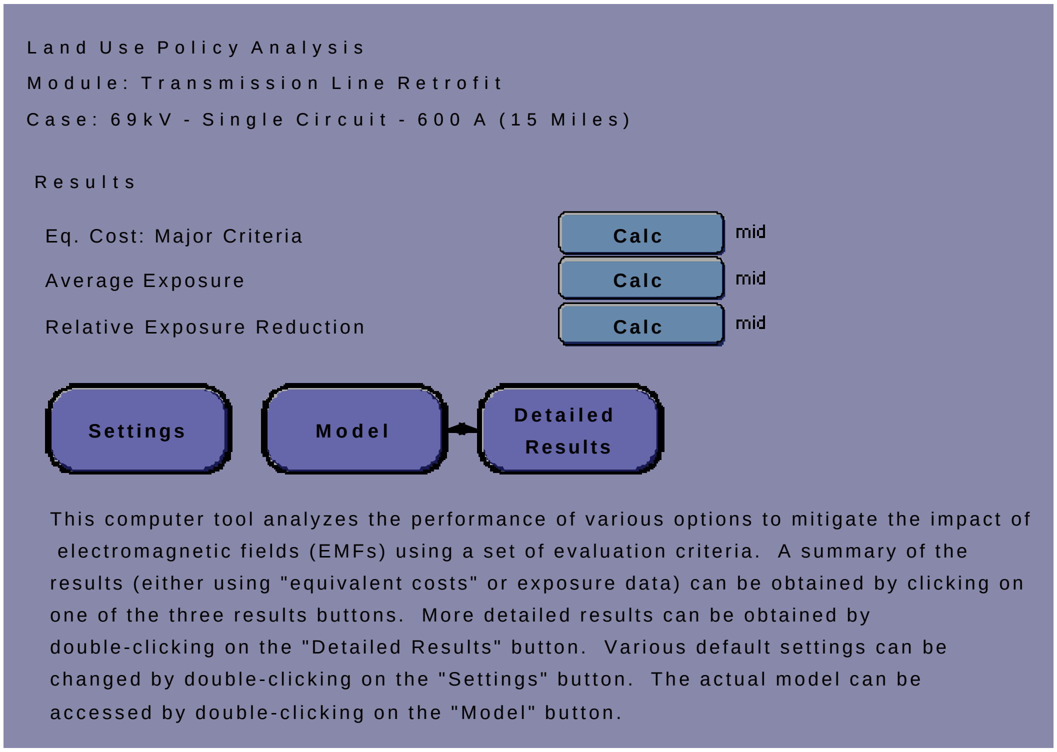


Figure 9: Opening Screen of the Analytica Models

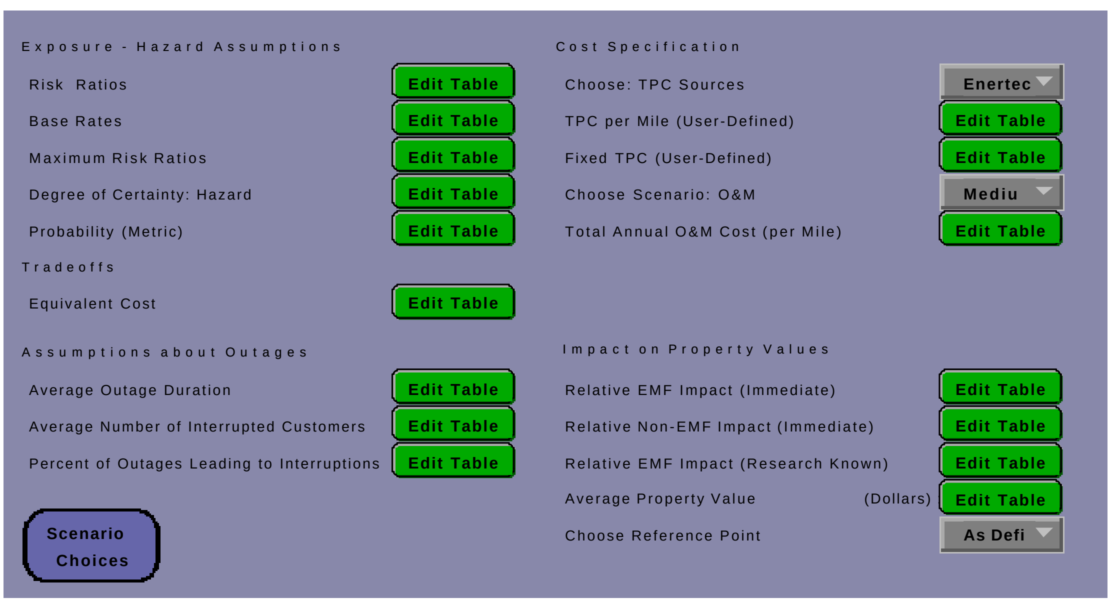


Figure 10: Settings Screen of the Analytical Models

Tables 8 and 9 show the equivalent cost of the EMF mitigation options under two alternative financial scenarios: Table 7 assumes 80% financing of the total project cost and 3% discounting of all costs, Table 8 assumes no financing and 3% discounting. In both tables we assumed a 10% degree of confidence of a relative risk of 2 for leukemia, brain cancer, breast cancer and Alzheimer’s Disease. The difference is striking: With financing, the split-phasing alternative is preferred, without financing, undergrounding is preferred.

Table 8: Equivalent Cost for 69 kV Transmission Line Retrofit

(3% Discount Rate, 80% of TPC Financed at 10% Interest)

Alternatives	Health-EMF	Cost	Outages	Property Values	Other	Total
No Change	$4,142,000	$4,596,000	$2,533,000	$0	$386,400	$11,657,400
Raise Pole Height	$3,375,000	$7,876,000	$2,533,000	$0	$402,200	$14,186,200
Underground	$413,600	$28,550,000	$656,300	-$12,640,000	$157,300	$17,137,200
Split Phase	$151,300	$7,190,000	$2,533,000	$0	$389,700	$10,264,000

Table 9: Equivalent Cost for 69 kV Transmission Line Retrofit

(3% Discount Rate, TPC Not Financed)

Alternatives	Health-EMF	Cost	Outages	Property Values	Other	Total
No Change	$4,142,000	$4,596,000	$2,533,000	$0	$386,400	$11,657,400
Raise Pole Height	$3,375,000	$6,251,000	$2,533,000	$0	$402,200	$12,561,200
Underground	$413,600	$17,110,000	$656,300	-$12,640,000	$157,300	$5,697,200
Split Phase	$151,300	$4,910,000	$2,533,000	$0	$389,700	$7,984,000

Figure 2 on page 10 illustrated how the choices between the three alternatives change with an increasing probability p that EMF is a hazard and an increasing risk ratio RR (reflecting the seriousness of the risk). Figures 11-13 show the two-way sensitivity analyses for different exposure measures, assuming financing of TPC and discounting. The results for the linear threshold at 2 mG (Figure 11) are virtually indistinguishable from the results of TWA without a threshold (Figure 2), because the largest contribution to health effects comes from the higher exposures, not from exposures below 2 mG. For the linear threshold at 5 mG the area of the preferred “No Change” is larger, because there are less health effects. Therefore, the degree of certainty that there is a hazard and the risk ratio must be larger before the health costs of “No Change” exceed the cost of mitigation. For the linear threshold at 10 mG, no change is the preferred alternative throughout the range of p and RR, because there are virtually no health costs for the “No Change” alternative. Graphs for the binary threshold measures are indistinguishable from the corresponding linear threshold graphs.

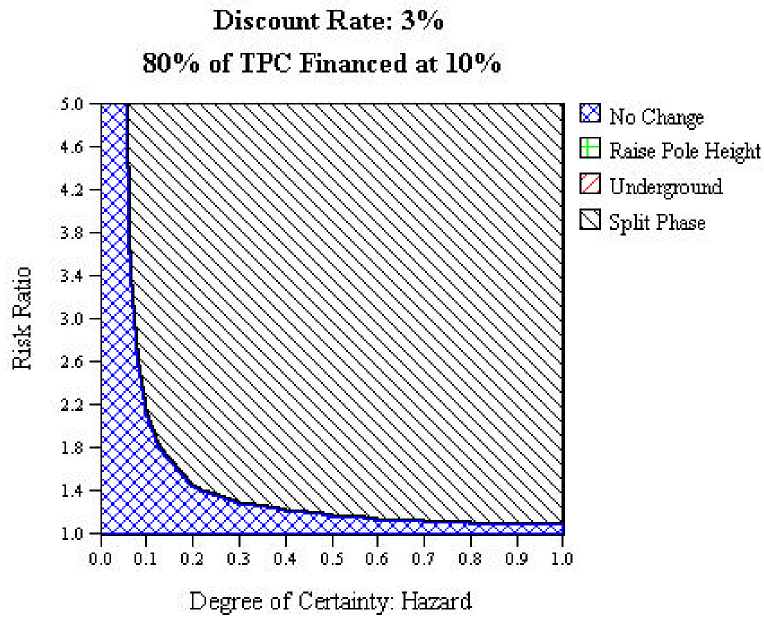


Figure 11: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit Using a Linear Threshold at 2 mG
(All Health Endpoints, TPC Not Financed, Property Values Included)

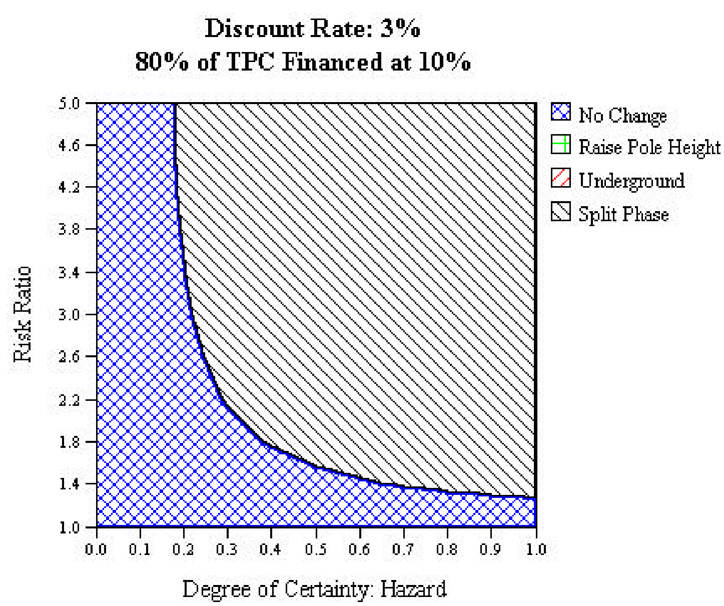


Figure 12: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit Using a Linear Threshold at 5 mG
(All Health Endpoints, TPC Not Financed, Property Values Included)

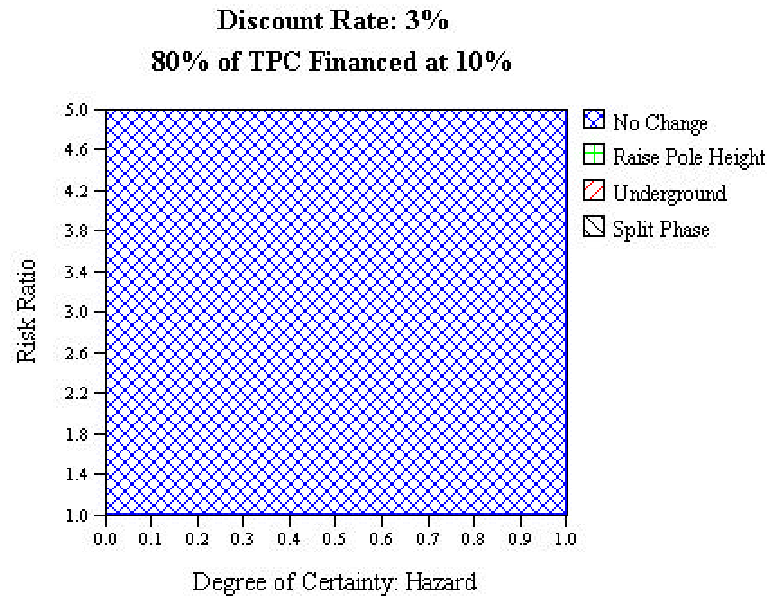


Figure 13: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit Using a Linear Threshold at 10 mG
(All Health Endpoints, TPC Not Financed, Property Values Included)

Figure 14 tells a quite different story: When assuming that total project costs are not financed, undergrounding is the preferred alternative for most values of p and RR. This is primarily due to the property values benefit of undergrounding. Split phasing is a winner for very high values of p and RR, because it is somewhat more effective in reducing EMF exposure than undergrounding (this particular scenario assumed that split phasing is combined with reverse phasing for maximum exposure reduction). At very high degrees of certainty and risk ratios, the cost and health reduction advantage of split phasing outweigh the property values advantage of undergrounding.

Many sensitivity analyses revealed that the preferred decision depends on the assumptions about financing, property values, and the number of health endpoints implicated in the possible EMF hazard. For example, when only leukemia is considered, TPC and property values are included, the preferred decision is to do nothing (Figure 15). When only leukemia is included as a health endpoint, TPC is not financed, and property values are not included, no change or split phasing are again the preferred alternatives, though the cross-over line shifts to the right relative to the cross over line in Figure 2, since the equivalent health costs are lower (Figure 16).

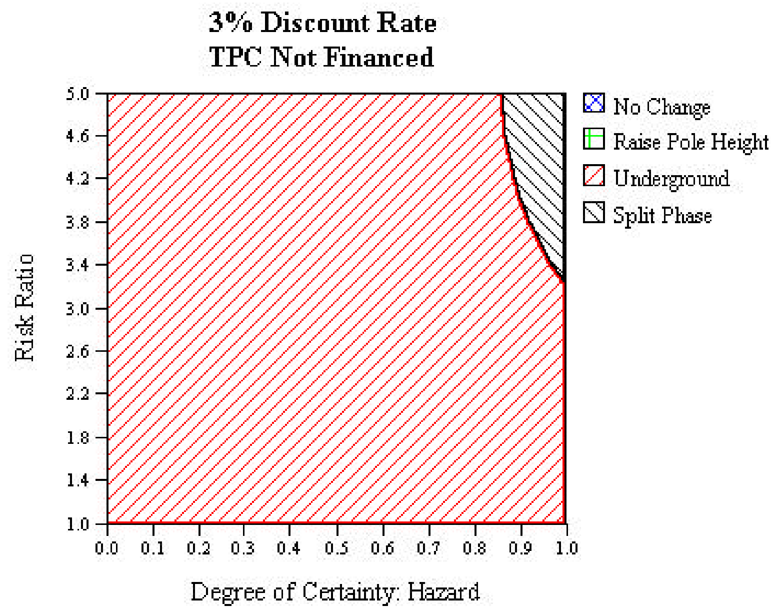


Figure 14: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(All Health Endpoints, TPC Not Financed, Property Values Included)

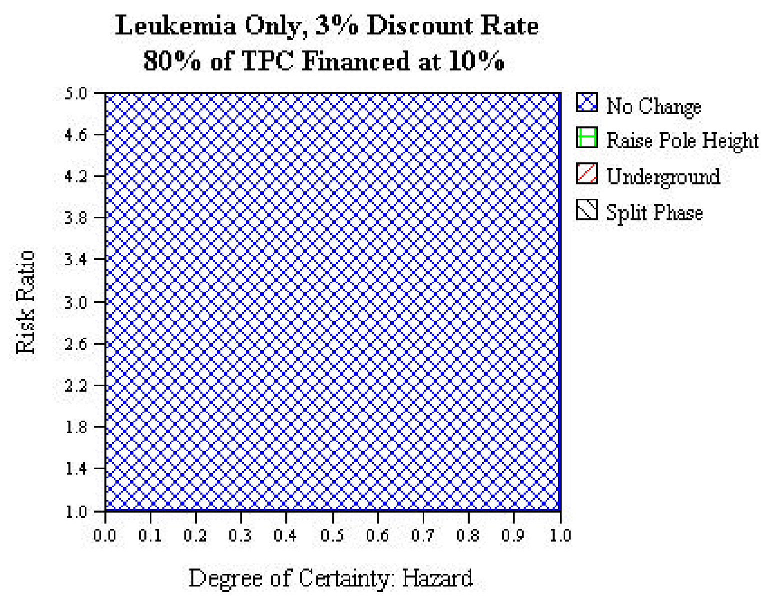


Figure 15: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(Leukemia Only, TPC Financed, Property Values Included)

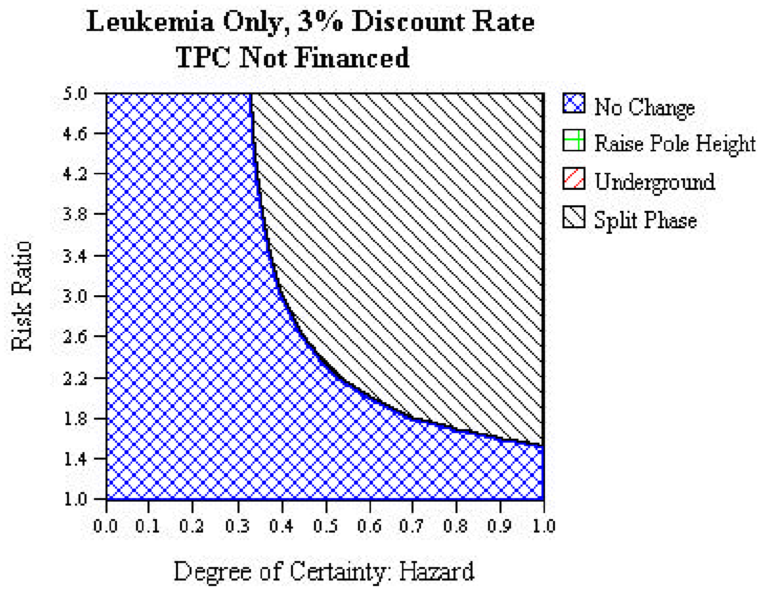


Figure 16: Two-Way Sensitivity Analysis on the Risk Ratio and the Degree of Certainty for 69kV Transmission Line Retrofit using TWA
(Leukemia Only, TPC Not Financed, Property Values Not Included)

Value of Information
(Final Report, Chapter 9)

Up to this point we considered choices among mitigation alternatives that would be implemented now or in the near future. A reasonable alternative may be to wait for research and then act according to the research outcomes. To investigate this issue, we developed a nation-wide value of information (VOI) model. This model led us to the conclusions that for most reasonable assumptions about possible health effects and mitigation costs, it is cost-effective to spend research funds in the millions of dollars per year to resolve the EMF issue. The reason for this conclusion is quite obvious. As long as the stakes are very high, even a very small probability of a serious health problem is worth investigating.

While it may be cost-effective to conduct EMF research, it may be more cost-effective to spend the same amount of money on other heath related research within the budget domain under the control of the Public Utilities Commission, for example, research into the possible effects of global warming from carbon dioxide emissions from generating plants or ways to avoid utility worker accidents. The cost-effectiveness of research into topics not relevant to the jurisdiction of the PUC or the utilities, such as any promotion of cardiovascular fitness, would not be relevant here, because they are not realistic alternative strategies for the PUC or for spending utility ratepayers' moneys. Our models do not compare the relative cost-effectiveness of EMF and non-EMF research.

Adherents to an Environmental Justice framework might advocate EMF research even if other more cost effective PUC funded research programs were available on the basis of a perceived ethical duty to do so.

Equity and Environmental Justice

(Final Report, Chapter 10)

The decision analysis approach used in this study does not lead to recommendations about resolving equity and environmental justice issues. However, it presents the analysis results in a way that allows examination of these issues and exploration of policies that address them. Most importantly, the results are always disaggregated so that the costs to groups that pay for EMF mitigation can be separated from the benefits accruing to other groups. Regarding the costs of mitigation, the analysis leaves many choices of how to distribute these costs among shareholders, ratepayers, and residents near power lines. These choices provide a powerful mechanism to address equity and environmental justice issues.

It is important to avoid the temptation to look at the “bottom line” of the analyses. The results are broken down by four criteria, which are associated with the costs and benefits accruing to different stakeholders:

1. EMF health effects – residents living near the powerlines
2. Costs – ratepayers, shareholders, or tax payers
3. Outages – all consumers of electricity
4. Property values – owners of properties near powerlines

Each mitigation alternative comes with estimated consequences in terms of EMF health effects, costs, outages, and property values. However, the mitigation alternatives do not specify the mechanism to finance the project cost. Policy makers therefore have significant control over financing mechanisms, if they decide to implement one of the mitigation alternatives. For example, they can decide to incorporate the cost of mitigation into the rate base, to have utilities (and thus their shareholders) pay for this without a rate increase, or to restrict payments to subsets of electricity users.

Each of these alternatives has significant equity and environmental justice implications. For example, when using a strict utilitarian view, undergrounding would be the preferred option in areas with high property value benefits, but it may not be a preferred option in areas with lower property value benefits. Such a result, when applied as a general policy, would clearly lead to inequities. Another example concerns the payment mechanisms for mitigation. When all ratepayers pay for mitigation, they will, in effect, pay restitution to people who have been negatively affected by the possible property value and health impacts of EMF exposure. They will also pay for the possible property values increase of those who bought homes that were devalued due to the EMF issue.

To illustrate how complicated this issue is, consider a homeowner who bought a house near a power line in 1960, well aware of the visual impacts of the line, but unaware of the EMF issue. A mitigation alternative that would lead to undergrounding the line would be appropriate, if EMF poses a health hazard, and it thus would provide a restitution of any loss of value of his house because of EMFs fears. However, it would also provide a "windfall" to the homeowner by eliminating the visual impacts of the powerline, which existed when the home was purchased – presumably at a reduced price. An owner who bought the house cheaply in 1990 during the height of the worries about EMF might receive a windfall in property values for both esthetic and EMF fear reasons, if the line is placed underground.

It is therefore not simply a matter of counting or not counting property values, it also is a matter of deciding who should pay for undergrounding, and who should benefit from the possible property value benefits of undergrounding. Similarly, if EMFs are not mitigated, and homeowners are successful in extracting restitution for any alleged losses in property values, decisions have to be made about who should receive the restitution (e.g., only homeowners who experienced a demonstrated loss due to EMF issues) and who should pay for it (e.g., shareholders and/or rate payers).

Environmental justice embraces equity and also addresses other moral and legal issues. The US Environmental Protection Agency defines environmental justice as follows:

> *"Environmental Justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. Fair treatment means that no group of people, including racial, ethnic or socioeconomic groups should bear a disproportionate share of the negative environmental consequences resulting from industrial, municipal, and commercial operations or the execution of federal, state, local, and tribal programs and policies."*

Environmental justice asks for special protection for the most vulnerable, the most susceptible, the poor, and people of color. This is not merely an equity issue but it invokes fundamental moral and ethical principles. The workshop on environmental justice held as part of this project addressed these issue. One of the key policy conclusions from this workshop was that racial and socioeconomic minorities should receive priority when making decisions about protecting health and well-being.

In the EMF context a major reason for giving racial and socioeconomic minorities this priority is that they often are exposed to higher levels of chemicals and other non-EMF pollutants. If EMF is a cancer promoter, they would be more likely to suffer from EMF exposure than other social groups. Also, the poor and people of color have less resources and access to medical care, so if they do suffer from health effects, either due to EMF or non-EMF sources, they are more likely to have longer effects or die than other social groups.

Statewide Policy Implications
(Draft Final Report, Chapter 11)

The models and analyses were developed in the context of specific scenarios for reducing exposures from transmission lines, distribution lines and home grounding systems. Typically, we used stretches of distribution and transmission lines between 4 and 50 miles, with detailed assumptions about land use, houses, and population density. We used this localized approach, because most real decisions about the electric power grid are made at this level. The intention was to first provide tools for local decisions and then provide guidance for rolling up the results to statewide land use and power grid policies, such as restricting land use, setting standards, etc.

In theory, this roll up is straightforward. First, the power grid system would be segmented into a much finer set of scenarios than was possible in this project. For example, a finer segmentation would include all voltage classes for transmission and distribution lines, more line configurations, more types of homes, land uses, etc. Second, the Analytica models would be used to analyze EMF alternatives at the scenario level and translated into per-mile costs and benefits. Third, a GIS type approach would be used to identify how many miles of the power grid system exist for each of the scenarios. Fourth, the per-mile results would be applied to the length of miles identified by the GIS analysis to provide an indication of the statewide costs and benefits of EMF policies.

With this idealized statewide roll up one can examine the effects of regulatory policies on local decisions and through the local decisions examine the cost and benefits implications of statewide regulatory policies. Regulatory policies are, in effect, driving local mitigation decisions. For example, if the policy is to implement low cost or no cost EMF mitigation, it will cause the implementation of alternatives like optimal phasing, compact delta configurations, and split phasing with their associated costs and benefits. If the policy is to set a field strength standard of 5 mG at the edge of the right-of-way in residential areas, it will lead to undergrounding for higher voltage transmission lines and some primary distribution lines. The Analytica models can provide the answer to the question: What is the best alternative within a specific scenario, given a statewide policy? These best alternatives and their costs and benefits can then again be rolled up to a statewide level to indicate the costs and benefits of the policy.

The analysis and computer tools that this project developed are suited for this kind of idealized statewide roll up. In practice, however, the few scenarios that we were able to run limit our statewide analysis. Thus, rather than relying directly on the results of the scenarios, we will use the scenario information to create rough low and high per mile estimates of the consequences of mitigation decisions. We will then examine different combinations of assumptions about low and high estimates (for example, assuming low total project cost, high health risk reduction benefits, and low property values benefits) to obtain a first impression of the impact of different assumptions. In addition, we will examine the implications of total project costs for policies that would be implemented on a statewide level.

Transmission Line Retrofitting. We analyzed three transmission line retrofitting scenarios: Retrofitting a 69kV transmission line on street side poles, retrofitting a 115 kV transmission line on a cleared 50 foot ROW, and retrofitting a 230 kV line on a cleared 50 foot ROW. The 69kV and 115 kV scenarios were located in a fairly dense suburban environment, the 230 kV scenario was in mixed residential, commercial, and rural environments.

We first noted that mitigation measures that were designed to reduce fields only at one or two spans of the line were generally inferior to mitigation measures that were applied to the whole line. We also noted that there typically was one "moderate" mitigation measure (optimal phasing or split phasing) with a relatively high degree of effectiveness in reducing EMFs at a relatively low cost. Undergrounding tended to reduce EMF exposures even more, but at a very high cost. Our statewide analysis therefore focuses on three alternatives:

1. No change,
2. Moderate action (split phasing or optimal phasing),
3. Undergrounding.

We analyzed the results of the three retrofitting models in terms of the equivalent per mile cost of three major consequences: Total Project Cost (TPC), Health Cost, and Property Values. Health costs include all health endpoints (leukemia, brain cancer, breast cancer, and Alzheimer's disease) considered in this study. Other direct costs (operation and maintenance, conductors losses, and outages) were also high in the scenarios analyzed, but they differed much less across alternatives, and thus are not as relevant for decision making. All costs are discounted at 3%. The low TPC costs assume no financing, while the high TPC costs assume financing. The health cost estimates include all diseases analyzed in this study (leukemia, brain cancer, breast cancer, and Alzheimers' disease). The low health costs assume a 5% chance that EMF poses a hazard for all diseases, the high costs assume a 20% chance. The low property values cost assumes that 100 homes adjacent to the line are appreciated at 5% when undergrounding, the high property values cost assume a 20% appreciation.

Tables 10 and 11 show two examples of the eight combinations of low or high TPC, health costs, and property value impacts. Table 10 shows the results, assuming low TPC, low health costs and low property values impacts. In this case, undergrounding has the lowest total equivalent cost for the 69kV line, while moderate change is preferred for the 115kV and 230kV lines. Table 11 shows the results, assuming high TPC, high health costs, and high property values impacts. In this case, undergrounding is preferred for the 69kV and 115kV lines, but is narrowly edged out by moderate change for the 230kV line.

Table 12 summarizes the results of analyzing all eight combinations of high or low TPC, health costs, and property values impacts. Clearly, the preference for no change, moderate action, or undergrounding is substantially affected by the choice of high or low cost assumptions. Generally, when property values impacts are assumed to be high, undergrounding is the preferred alternative, except for 230 kV lines. In most other cases, moderate action is preferred, except when TPC is high, and health and property values impacts are low. In this case, no change is preferred. There is also a trend to prefer more stringent action for lower voltage classes than for higher ones, because the retrofitting costs are higher for higher voltage classes.

Table 10: Per Mile Equivalent Costs for Major Criteria
(Low TPC, Low Health Cost, Low Property Values Impacts)

69 kV Retrofit	**TPC**	**Health**	**Prop. Values**	**Total**
No Change	$0	$125,000	$0	$125,000
Moderate Change	$150,000	$5,000	$0	$155,000
Undergrounding	$750,000	$12,500	-$1,000,000	-$237,500
115 kV Retrofit				
No Change	$0	$350,000	$0	$350,000
Moderate Change	$200,000	$60,000	$0	$260,000
Undergrounding	$1,500,000	$6,000	-$1,000,000	$506,000
230 kV Retrofit				
No Change	$0	$1,000,000	$0	$1,000,000
Moderate Change	$500	$500,000	$0	$500,500
Undergrounding	$3,000,000	$10,000	-$1,000,000	$2,010,000

Table 11: Per Mile Equivalent Costs for Major Criteria
(High TPC, High Health Cost, High Property Values Impacts)

69 kV Retrofit	**TPC**	**Health**	**Prop. Values**	**Total**
No Change	$0	$400,000	$0	$400,000
Moderate Change	$300,000	$20,000	$0	$320,000
Undergrounding	$1,500,000	$50,000	-$4,000,000	-$2,450,000
115 kV Retrofit				
No Change	$0	$1,400,000	$0	$1,400,000
Moderate Change	$4,000	$240,000	$0	$244,000
Undergrounding	$3,000,000	$24,000	-$4,000,000	-$976,000
230 kV Retrofit				
No Change	$0	$4,000,000	$0	$4,000,000
Moderate Change	$1,000	$2,000,000	$0	$2,001,000
Undergrounding	$6,000,000	$40,000	-$4,000,000	$2,040,000

Table 12: Summary of Results of Sensitivity Analyses on High and Low Cost Scenarios for TPC, Health, and Property Values

(UG=Undergrounding, MC=Moderate Change, NC=No Change)

Cost Scenario			Preference by Voltage Class		
TPC	**Health**	**Prop. Values**	**69kV**	**115kV**	**230kV**
Low	Low	Low	UG	MC	MC
High	Low	Low	NC	NC	NC
Low	High	High	UG	UG	MC
High	High	High	UG	UG	MC
Low	High	Low	UG	MC	MC
High	High	Low	MC	MC	MC
Low	Low	High	UG	UG	UG
High	Low	High	UG	UG	MC

From the GIS analysis of transmission lines, we can calculate the number of circuit miles of transmission lines of several voltage classes that pass through residential, commercial, industrial, or rangeland and other areas (see Table 13). It is clear from this table that the vast majority of transmission lines are located outside of residential, industrial, and commercial areas.

Table 13: Miles of Transmission Lines by Land Use

	69 kV (60-92)	**115 kV** (110-161)	**230 kV** (220-287)
Residential	884	867	753
Commercial/Industrial/Mixed	496	457	491
Other (Agricultural, Rangeland, etc.)	13,460	9,028	11,386
Total	14,840	10,352	12,630

It is tempting to multiply the per-mile estimates from tables like Tables 10 and 11 by the residential miles of transmission lines displayed in Table 13 to obtain state-wide estimates. However, the GIS database shows circuit miles rather than structure miles or corridor miles. Circuit miles are the miles of usually three cables that connect two substations. In many cases, two circuits are placed on one structure as can be seen in many transmission line towers, which carry six cables – three on each side. These are called double-circuit lines and we refer to double circuit miles. Sometimes, multiple structures are placed in the same corridor, in which case we refer to them as corridor-miles. While it is appropriate to estimate TPC on the basis of circuit miles (taking care to distinguish between single circuit and double circuit lines), we would overestimate effects and property values impacts, which should be based on corridor miles.

There is very little data on the percentage of transmission lines, which are double circuit vs. single circuit. One of our consultants gave some very rough estimates for one major utility that suggested that most 230kV lines are double circuit, while most 69 kV lines are single circuit. The 115 kV lines are about evenly split between single and double circuit lines. In our statewide cost estimates, we assume that all 69kV lines are single circuit and all 115kV and 230kV lines are double circuit. This will overestimate the cost of retrofitting the 69kV lines somewhat, while underestimating the cost of retrofitting the higher voltage class lines. Based on these assumptions, and using our scenario calculations as a guide for cost estimates, we created low and high cost estimates for retrofitting transmission lines statewide (see Table 14). The Moderate Change case costs $135.6 million for the low TPC and $272 million for the high TPC case. Undergrounding costs $2,475 million for the low TPC case, $4,950 million for the high TPC case.

Table 14: Statewide Estimate of Costs of Moderate Change and Undergrounding Transmission Lines

Moderate Change	**Low TPC**	**High TPC**
69kV	$135,000,000	$270,000,000
115 kV	$400,000	$1,600,000
230 kV	$200,000	$400,000
Total	**$135,600,000**	**$272,000,000**
Underground	**Low TPC**	**High TPC**
69kV	$675,000,000	$1,350,000,000
115 kV	$600,000,000	$1,200,000,000
230 kV	$1,200,000,000	$2,400,000,000
Total	**$2,475,000,000**	**$4,950,000,000**

We stated earlier that the impact of the EMF issue on property values of homes near transmission lines is very hard to quantify. However, a few calculations are illustrative. For example, using the miles of transmission lines in Table 13 and the simple rule of counting single vs. double circuit lines, we calculate approximately 1,700 miles of transmission line corridors that pass through residential areas in California. Assuming 100 homes per mile adjacent to the corridor (50 on each side), 170,000 homes would be affected. Further assuming an average property value of $200,000, the total property value of these homes is $34 billion. A 1% depreciation of these properties would amount to $340 million, a 20% depreciation to $6.8 billion. At the low end, this property value impact is only about 5-10% of the TPC of undergrounding, but at the high end, this could be commensurate to the TPC of undergrounding.

The EMF debate started in 1979, with Wertheimer and Leeper's publication and it became a publicly debated issue in the late 80's, when additional epidemiological findings were published and the media started to pay attention to the issue.

Consequently, there are many homeowners, who owned a home near a transmission line, and still own it today. In fact, since the median length of homeownership in California is about 12 years, we estimate that about 50% of the 170,000 homes are still owned by those who owned it prior to EMF becoming a debated public issue. If these homeowners appealed to the PUC to obtain restitution for lost property values and if the PUC complied with the appeal, the total cost of this restitution would range from $170 million to $3.4 billion depending on the percent of depreciation (1% vs. 20%). Some of the stakeholders assumed that any such restitution would be spread to all ratepayers and that undergrounding should be credited with avoiding this cost.

The transmission line retrofitting models have examined only a limited set of engineering measures to reduce EMF exposure (split phasing, optimal phasing, raising pole height, and undergrounding). In addition, we analyzed local mitigation options (e.g., for one or two spans of the line) of each of the mitigation alternatives. Even though we analyzed only a limited set of alternatives formally in the Analytica models, we conducted an informal screening of many more alternatives, and typically found them infeasible or a priori not likely to be cost-effective. In the following paragraphs we discuss the local options and some of the screened out options from a statewide perspective.

We generally found that retrofitting only a few spans of transmission lines was not very cost-effective, because too few people benefited from the EMF reductions. Nevertheless, equity and environmental justice considerations may require policy makers to pay special attention to some stretches of power lines, if they expose sensitive individuals, poor people, and communities of color.

A second version of mitigating only a few stretches of powerline is to mitigate only in high-density residential areas. However, we generally found that moderate mitigation can be cost-effective both for higher and lower population densities. This option also raises ethical and environmental justice issues. People living in low-density population areas would certainly raise the question of why they do not receive equal protection.

One could also consider mitigating only in residential areas, but not in industrial or commercial areas. We have not run commercial or industrial land uses separately with our models, but we would expect moderate options to be cost-effective for them as well, though less so than for residental areas. The main factors contributing to less effectiveness are the lower population densities and shorter periods of exposure.

Increasing the right-of-way (ROW) is usually either impractical or prohibitively expensive in residential areas. In most residential areas, homes are built up to the existing ROW (usually about 50 feet from the center of the transmission line). Increasing the ROW by, say 50 feet would encroach on existing properties and require purchase of land and homes. In all of our scenarios, the cost of purchasing one row of homes on each side of the transmission line would have been prohibitive. For example, purchasing one row of 50 homes on each side of a transmission line at a cost of $200,000 per home would cost $20 million, much higher than the cost of undergrounding. As our new transmission line scenarios show, increasing the ROW is also not very cost-effective in reducing EMF exposure.

Creating larger set backs for currently undeveloped areas than for the developed ones is likely to be less expensive, but this option has other problems. First, it could possible stigmatize the homes that are closer to transmission lines and lead to additional property value losses. These losses are almost certainly going to be higher than the health risk reduction benefits due to the new setbacks. Second, there are equity problems associated with this option. For example, should the developers be compensated for reducing their space for development and should the homeowners with a lesser setback be compensated for property value losses due to stigmatization?

Electricity conservation is a potentially attractive option, since the costs to the individual customer can be small. We ran some preliminary models with a 10% conservation rate for both residential and commercial customers. We found that EMFs would be reduced roughly in proportion to the reduction of electricity use with the associated proportional decrease in possible health risks and costs. Of course, the main benefit of conservation was the direct savings in electricity bills, which is larger that the imputed reduction of health effects from EMF exposure or pollution.

There are many different types of standards for EMF exposure, including ROW field strength standards and various types of exposure standards. Examining the outputs of our exposure programs provides some insights about the implications of these standards for mitigation, and, as a result, for the costs and benefits of standard setting alternatives. For example, requiring a 2mG field strength standard at the edge of a transmission line ROW, would likely force utilities to underground all transmission lines, while a 20mG standard would only require to underground lines above 230kV and possibly require some moderate actions for lower voltage lines.

For new transmission lines ROW field strength standards have been implemented in some states. However, no state currently requires standards for existing transmission lines. Our exposure analyses lead to the following insights regarding these standards:

1. Field strength standards above 100mG at 50 feet will not require mitigation with the possible exception of 350kV and 500 kV lines.

2. Field strength standards in the neighborhood of 50mG at 50 feet may require mitigation for transmission lines with rated ampacities of 1,000 A, but in many cases, the standard can be achieved by moderate actions.

3. Field strength standards of 10 mG at 50 feet may require undergrounding of some stretches of lines with rated ampacities of 1,000 A or more, but the standard can probably be met with moderate actions for most other lines.

4. Field strength standards below 5 mG at 50 feet may be difficult to meet without undergrounding a significant part of the transmission line system.

Exposure standards (e.g., average milliGauss exposure per person per day) pose additional practical problems. It is very hard to measure exposure of individuals, and it is even more difficult to determine whether an individual exposure standard has been exceeded. In addition, the questions arise, what exposure measure should be used, whether background exposure should be counted, and what time frame to use for exposure.

Some ROWs are accessible as jogging paths, parks, and some even include children's playgrounds. One regulatory option is to eliminate public uses. Our models suggest that exposure in ROWs may be very high, but that the time of exposure in ROWs will be fairly short. Additional modeling would be required to determine the incremental risks of these short-term exposures under different assumptions and parameters. A simple regulatory option is to post warning labels at or near sources of high EMF fields. The implications of these warning labels on people's behavior, on assumed responsibility, and liability have yet to be studied. Our analysis does not provide any insights in this regard.

Many utilities provide information packets about EMF exposure to customers. These packets typically inform customers about the sources of EMF exposure and they discuss the inconclusive state of research. Our models do not address the effectiveness of information options.

We found that research on a possible EMF health link is valuable, as long as three conditions are met:

1. the equivalent costs of health effects exceed the cost of mitigation;
2. the mitigation costs are fairly expensive;
3. alternative environmental and health research priorities under the control of the utility industry are not more cost beneficial.

The first two conditions are met, even if we only consider the transmission line system in California. The third condition is open to contention.

Siting and Configuring New Transmission Lines. We analyzed three transmission line configurations for a new 115kV line: Triangular post, split phase, and undergrounding. The primary purpose of these scenarios was to examine the effects of two land use alternatives: Selecting routes with lower population density and increasing the ROW. An additional purpose was to determine the effects of siting a new 115 kV transmission line with an existing 33kV underbuilt line.

The key insights are that the differential costs of the land use alternatives (different routes and different sizes of the ROW) dominate the differences between the engineering mitigation options. In the case of different routes, the shorter route has the advantage of lower total project costs, partly because of lesser structures and construction costs, partly because of lower land acquisition costs. In the case of different ROWs, the smaller ROW has the advantage of substantially lower land acquisition costs.

One can achieve some decreases in expected health effects by re-routing and increasing the ROWs, but these decreases are small compared to the decreases that one can achieve by split phasing or undergrounding. In most scenarios split phasing (with shorter routes and smaller ROWs) is the preferred option under many assumptions.

The major limitation of these scenarios for generalization to a statewide policy level is that split phasing is not always possible. For example, when building a 230 kV line, the structures are typically designed to carry two circuits. We assume, without having run a specific scenario, that reverse phasing is a cost-effective mitigation strategy in this case.

Another limitation is that we have not fully analyzed the effect of building a new transmission line on the loads and corresponding EMF exposures on other lines in the local grid. Keeney (1997) makes the point that building a new line may in fact decrease health risks under some conditions. For example, re-distributing the loads between the existing and the new line could actually reduce the total number of people exposed above a threshold. We have run an exposure model that confirms Keeney's theoretical calculations, but we have not embedded these results in a full Analytica model.

Deciding on whether to upgrade an existing line versus building a new one, how to route the line, and what ROW to choose has profound equity and environmental justice implications. Clearly the exposure and risk equity issue is pertinent for deciding on whether to upgrade or to build a new line. Building a new line will have significant impacts on residents and homes along the new route. Increasing the ROW for new lines could lead to stigmatization of homes near smaller ROWs. Because of these equity and environmental issues, it is particularly important that environmental justice principles and processes be followed when upgrading or building new lines (see chapter 10).

Increasing the tower or pole height has only limited exposure reduction effects compared to split phasing, reverse phasing and undergrounding. Local alternatives (e.g., re-routing around schools) also have limited effects, but environmental justice concerns may override the cost-benefit considerations. Conservation could reduce the need for upgrading existing lines or building new lines.

The regulatory policies discussed previously (retrofitting existing transmission lines) apply to new transmission lines as well. In particular, low field strength standards at the edge of ROW will force either split phasing, reverse phasing, or undergrounding, depending on the numerical value of the standard and the configuration, voltage class, and loads on the line. If warning labels or other information are provided for new transmission lines, it would only be natural to provide them also for existing transmission lines. Continuing research is likely to be valuable under many assumptions.

Distribution Line Retrofitting. We analyzed two retrofitting scenarios for distribution lines. Both are for four-mile stretches of primary distribution lines, one with a four-wire configuration and one with a three-wire configuration. As with the transmission line retrofitting scenarios, we observed that for all model runs the options that mitigated only a few spans of the distribution lines were inferior to those that mitigated the whole line. Consequently, we will only generalize from the "whole line" scenarios. In addition, we noticed that all results from the two scenarios are identical, except for health effects, which are somewhat higher for the three-wire configuration. Finally, we noticed that the most cost-effective "moderate action" alternative seems to be conversion to a compact delta configuration.

We calculated the equivalent per mile cost of three major consequences: Total Project Cost (TPC), Health Cost, and Property Values. Other direct costs (operation and maintenance, conductor losses, and outages) were also high in the scenarios analyzed, but they differed much less across alternatives, and thus are not as relevant for decision making. All costs were discounted at 3%. The moderate action is to convert the line to a compact delta configuration. The low TPC costs assume no financing, while the high TPC costs assume financing. Health costs included all diseases considered in this study (leukemia, brain cancer, breast cancer, and Alzheimer's disease). The low health costs assume a 5% chance that EMF poses a hazard for all health end points, the high costs assume a 20% chance. The risk ratio was assumed to be 2 at 2 mG or an equivalent exposure level. The low property values cost assumes that 100 homes adjacent to the line are appreciated at 2.5% when undergrounding, the high property values cost assume a 10% appreciation.

Table 15 shows the results, assuming low TPC, low health cost, and low property values impacts. In this case moderate action is the preferred (lowest cost) alternative. Table 16 shows the results, assuming high TPC, high health costs, and high property values impacts. In this case, undergrounding is the preferred alternative. In general, the conclusion from analyzing the eight combinations of low and high costs are very straightforward: When property value impacts are assumed to be low, moderate action is preferred. When property values are assumed to be high, undergrounding is preferred. Thus, the results depend only on the assumptions about the property value benefits of undergrounding.

Table 15: Per Mile Equivalent Cost of Retrofitting Distribution Lines
(Low TPC, Low Health Cost, Low Property Values Impacts)

	TPC	**Health**	**Prop. Values**	**Total**
No Change	$0	$150,000	$0	$150,000
Moderate Change	$35,000	$25,000	$0	$60,000
Undergrounding	$750,000	$2,500	-$500,000	$252,500

Table 16: Per Mile Equivalent Cost of Retrofitting Distribution Lines
(High TPC, High Health Cost, High Property Values Impacts)

	TPC	**Health**	**Prop. Values**	**Total**
No Change	$0	$600,000	$0	$600,000
Moderate Change	$70,000	$100,000	$0	$170,000
Undergrounding	$1,500,000	$10,000	-$2,000,000	-$490,000

Table 17 shows the statewide estimates of the low and high total project costs. If we assume that 6,700 miles (see page 13) require retrofitting, these costs range from $5 billion to $10 billion.

Table 17: Statewide Estimates of Costs of Retrofitting Distribution Lines

6,700 miles	**Low TPC**	**High TPC**
Moderate Change	$234,500,000	$469,000,000
Undergrounding	$5,025,000,000	$10,050,000,000

A few calculations on the potential impact of the EMF issue on property values of homes near distribution lines are again illustrative. Assuming that 6,700 miles of distribution lines produce elevated fields and that 50 homes per mile are adjacent to the distribution line about 335,000 homes could be affected. Further assuming an average property value of $200,000, the total property value of these homes is $67 billion. A 1% depreciation of these properties would amount to $670 million, a 10% depreciation would amount to $6.74 billion. At the low end, this property value impact is only about 10%of the TPC of undergrounding, but at the high end, it is close to the cost of undergrounding. About 50% of the homeowners lived in their homes when the EMF debate became a public issue (about 10-15 years ago). If these homeowners appealed to the PUC to obtain restitution for losses in property values and if the PUC complied with the appeal, the total cost of this restitution would range from $335 million to $3.4 billion depending on the percent of depreciation (1% vs. 10%). Some of the stakeholders assumed that any such restitution would be spread to all ratepayers and that undergrounding should be credited with avoiding this cost.

As in the transmission line scenarios, mitigating a few stretches of distribution lines did not seem very cost-effective and it had negative equity and environmental justice implications. Increasing the ROW is often impossible for distribution lines. These lines are primarily located on the street side or in backyard areas and they can run very close to homes. Conservation will have a health effect impact by reducing the effects roughly proportional to the reduction of electricity consumption.

Field strengths in the close vicinity of primary distribution lines can be as high as 10 mG. Standards in the neighborhood of 5mG may require conversion to compacts delta configurations or undergrounding of long stretches of primary distribution lines. Exposure standards are impractical for reasons discussed in the transmission line section. Restriction of the access to the ROW is difficult, because there are so many different activities that occur in backyards, fronts of home and on street sides. Providing warning labels and information may be a useful policy to educate residents and to assure that they make simple arrangements to avoid extended exposure in high field areas. Research is even more valuable for distribution line issues than for transmission lines, since more is at stake.

We have not explicitly modeled the effects of secondary distribution lines. However, the main EMF exposure from secondary distribution lines will occur at the service drop, and our home grounding models capture this effect.

Home Grounding Systems. The home grounding models were run for individual houses, since most decisions are made at that level. The analyses only concerned homes with elevated fields due to net currents on the water pipe. According to Zafanella (1993) between 5% and 10% of U.S. homes have such elevated fields. Using many assumptions and parameter values, the general finding was that for homes with elevated fields from home grounding systems, insulating the water pipe by inserting a piece of plastic pipe was the preferred option. A homeowner can eliminate the incremental risk from this elevated field by insulating the water pipe in this way, for a cost between $200 and $500.

Table 18 shows the equivalent costs for one of the home grounding models. In both the low cost and the high cost scenario, insulating the pipe is the preferred option. Health costs were estimated using all diseases considered in this study, a degree of certainty that a hazard exists of 0.10 and a risk ratio of 2. The time horizon in this case was ten years, roughly the length of home ownership in California. Table 19 shows the implications of applying these low and high costs to either 5% or 10% of the homes in California. These costs are fairly small compared to the costs of retrofitting transmission and distribution lines. We also analyzed improving the net return or changing living arrangements. Under most reasonable assumptions insulating the pipe is the preferred option.

Table 18: Equivalent Costs Retrofitting the Home Grounding System (Single Home)

High Cost Scenario	**Health**	**Cost**	**Total**
Do Nothing	$562	$0	$562
Insulate Pipe	$0	$500	$500
Low Cost Scenario	**Health**	**Cost**	**Total**
Do Nothing	$562	$0	$562
Insulate Pipe	$0	$200	$200

Table 19: Equivalent Cost of Retrofitting Home Grounding Systems (California)

	Low Cost	**High Cost**
5% of Homes	$110,000,000	$275,000,000
10% of Homes	$220,000,000	$550,000,000

It is tempting to conclude from our model runs that a reasonable regulatory policy would be to recommend to homeowners to insulate the water pipe, if their homes have elevated fields from grounding system. However, there are two caveats: First, depending on the degree on certainty that EMF is a hazard, this may in fact, not be the best option. Second, there may be indirect risks as a consequence of insulating the pipe, including electrocution hazards and increased fire hazards (see von Winterfeldt and Trauger, 1996).

Cost estimates for All Sources. Table 20 is a summary of cost estimates for all sources of EMF exposure to the 2.6 million people mentioned in Table 6 using the low estimates of retrofitting costs. Table 21 shows the same estimates using the high cost estimates. Tables 22 and 23 shows these results in terms of percent of ten years of utility revenues of the sort experienced in the 1990's and in terms of the number of deaths that would need to be avoided to make retrofitting a preferred alternative. Ten years of revenue were used on the assumption that it would take at least a decade to accomplish any of the retrofits discussed.

Table 20: Unit and Statewide Estimates of the Costs of EMF Mitigation (Low Cost Estimates)

Source	Miles/Homes	Cost/Unit (Mile or Home)		Statewide Cost	
		Moderate	Underground	Moderate	Underground
Transmission (69 kV)	900 miles/sgl. circuit	$150,000	$750,000	$135,000,000	$675,000,000
Transmission (115 kV)	400 miles/dbl. circuit	$2,000	$1,500,000	$800,000	$600,000,000
Transmission (230 kV)	400 miles/dbl. circuit	$500	$3,000,000	$200,000	$1,200,000,000
Distribution	6,700 miles	$35,000	$750,000	234,500,000	$5,025,000,000
Home Grounding	550,000 homes	$200	$200	$110,000,000	$110,000,000
TOTAL				**$480,500,000**	**$7,610,000,000**

Table 21: Unit and Statewide Estimates of the Costs of EMF Mitigation (High Cost Estimates)

Source	Miles/Homes	Cost/Unit (Mile or Home)		Statewide Cost	
		Moderate	Underground	Moderate	Underground
Transmission (69 kV)	900 miles/sgl. circuit	$300,000	$1,500,000	$270,000,000	$1,350,000,000
Transmission (115 kV)	400 miles/dbl. circuit	$4,000	$3,000,000	$1,600,000	$1,200,000,000
Transmission (230 kV)	400 miles/dbl. circuit	$1,000	$6,000,000	$400,000	$2,400,000,000
Distribution	6,700 miles	$70,000	$1,500,000	469,000,000	$10,050,000,000
Home Grounding	550,000 homes	$500	$500	$275,000,000	$275,000,000
TOTAL				**$1,016,000,000**	**$15,275,000,000**

Table 21: Statewide Costs Expressed as a Percent of Utility Revenues and Lives Saved Required to Justify Mitigation Cost (Low Cost Estimates)

Source	Statewide Cost		Percent of 10 Year Revenue		Lives Saved to Justify Cost*	
	Moderate	Underground	Moderate	Underground	Moderate	Underground
Transmission	$136,000,000	$2,475,000,000	0.06%	1.13%	27	495
Distribution	234,500,000	$5,025,000,000	0.11%	2.28%	47	1,005
Home Grounding	$110,000,000	$110,000,000	0.05%	0.05%	22	22
TOTAL	**$480,500,000**	**$7,610,000,000**	**0.22%**	**3.46%**	96	1,522

*Over 35 years assuming $5 million/life

Table 22: Statewide Costs Expressed as a Percent of Utility Revenues and Lives Saved Required to Justify Mitigation Cost (High Cost Estimates)

Source	Statewide Cost		Percent of 10 Year Revenue		Lives Saved to Justify Cost*	
	Moderate	Underground	Moderate	Underground	Moderate	Underground
Transmission	$272,000,000	$4,950,000,000	0.12%	2.25%	54	990
Distribution	469,000,000	$10,050,000,000	0.21%	4.57%	94	2,010
Home Grounding	$275,000,000	$275,000,000	0.13%	0.13%	55	55
TOTAL	**$1,016,000,000**	**$15,275,000,000**	**0.46%**	**6.94%**	203	3,055

*Over 35 years assuming $5 million/life

Conclusions and Caveats

As stated in the introduction, the objective of this project was to provide decision-makers with analysis and computer tools to examine the consequences of alternative policies to reduce EMF exposure from California power grid sources. The project created three analysis and computer tools:

1. an exposure model,
2. a set of decision analysis models in Analytica
3. a set of simplified decision analysis models in EXCEL (described in a supplementary document by von Winterfeldt, 2001)

These tools were designed so that a user can examine any scenario for decisions and policies about mitigating EMF exposures from power grid sources. The tools were highly parameterized to allow users to input their own data and estimates.

The models were illustrated with ten scenarios. Sensitivity analyses were conducted to determine which assumptions and parameter values made a difference to the decisions about mitigating EMF exposure.

In the process of exercising the models in specific scenarios, we gained several insights. Perhaps the most important one was that only four criteria had a major impact on the decisions:

1. EMF health effects,
2. direct costs to utilities (primarily total project cost)
3. outages,
4. property values.

This result is consistent with Sage's (1999) analysis, which was performed for stakeholders representing residents living near transmission lines. The fact that we could narrow down the impacts of EMF mitigation options is important, because it helps to focus the policy debate on the criteria that matter.

Another result of exercising the models was that moderate options (optimal phasing, split phasing, compact delta configurations) were attractive under many assumptions and parameter values, because they led to significant exposure reductions at a fairly low cost. Undergrounding also can be an attractive option, if it creates property values impacts commensurable with the total project costs.

Which of the three contenders (no change, moderate engineering change, or undergounding) is best, depends on the stakeholder choices of model parameters and assumptions. The "No Change" alternative is best when stakeholders make the following choices:

- financing of the cost of mitigation
- low discount rate for financed TPC
- high discount rate for health costs
- leukemia as the only health endpoint
- low estimates of the probability of hazard and the risk ratio
- low value tradeoffs for health risks
- large multipliers for the costs of mitigation
- low or no property value impacts

Undergrounding is favored when making the following choices:

- no financing of the costs of mitigation,
- high discount rates for financed TPC
- low discount rate for health costs
- all health endpoints
- high estimates of the probability of hazard and the risk ratio
- high value tradeoffs for health risks
- base case cost or low cost multipliers for undergrounding
- high property values impacts

For most intermediate choices, the moderate engineering changes (optimal phasing, reverse phasing, split phasing, or compact delta) are favored by the analyses.

Waiting for research can be an appropriate strategy under some conditions. Furthermore, the value-of-information analysis shows that it may be reasonable to fund research at a fairly substantial level.

There are several caveats that temper these conclusions. First, most conclusions are based on the assumption that there is some probability of a health hazard due to EMF. Second, many conclusions about the value of undergrounding depend on assuming property values depreciations or appreciations, which are still widely disputed. Third, many estimates were based on conservative assumptions made to magnify the potential impact of a criterion on the decision. Fourth, this analysis was based on very limited knowledge on the number of homes affected by transmission and distribution lines and the number of transmission and distribution lines that may be candidates for EMF mitigation.

Several factual issues were matters of intense debate among the stakeholders and little information was available, or the information was considered proprietary by the utilities. In some cases this study had to rely entirely on the utility companies to provide this information. The model allows assumptions within the range of estimates favored by different stakeholders. If the different estimates lead to different policy options, the only solution is for the PUC to have a mutually accepted third party provide reliable information on the following issues:

1. the cost of retrofitting existing lines as a function of soil condition and land use, and other factors
2. the reliability of overhead and underground transmission and distribution lines as a function of age and type of technology
3. the conductor losses from operating existing and new lines as a function of line and cable type
4. the operation and maintenance costs of different types of lines

In addition, the following information would be useful to improve the statewide roll up:

1. the number of corridor miles of transmission and distribution lines in California that produce elevated fields in homes
2. a categorization of the corridor miles in 1) as to the number of circuits and types of lines (voltage class, overhead vs. underground), with associated miles per category
3. the number of homes in California that are exposed to elevated fields

Once this information is acquired it can be inserted into the decision models to determine, if the conclusions would be altered.

The ultimate test of the analysis and computer tools is to put them to use in real policy and mitigation decisions. The generalizations described in this chapter still need to be confirmed with many more scenarios and many more model runs. The project has provided the tools for doing this. To develop policies with these models, decision makers will need to develop experience with exercising them, conducting sensitivity analysis from various stakeholders’ perspectives, and use judgment to form policies. More importantly, the analyses have to be improved by collecting additional information as outlined above.

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